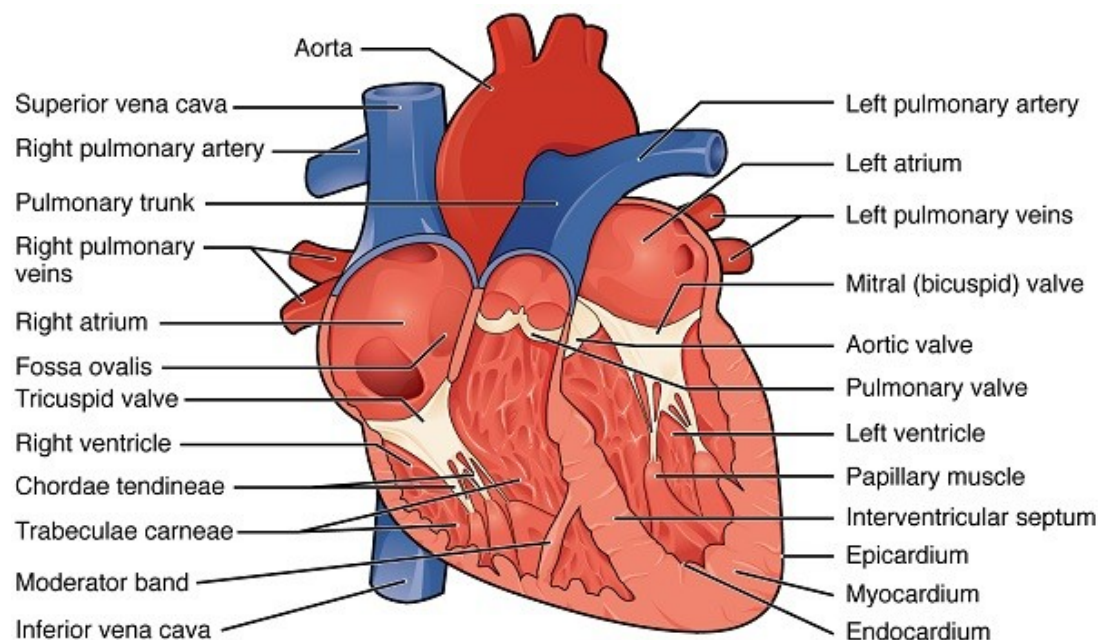


## Anatomy & Pathology of the Heart and Components of the Cardiovascular System

[See online here](#)

The heart is a hollow muscular organ that contracts approx. 100,000 times a day and pumps approx. five liters of blood into the circulation every minute. It is not only characterized by the unique features of muscle tissue specialized to meet the constant physical demands of pumping blood, but also by muscle cells that send spontaneous rhythmic electrical impulses to stimulate contraction. This article gives an overview of the structure of the heart wall and of cardiac muscle tissue.



### Layers of the Heart Wall

The layers of the heart wall and the blood vessels have the same basic structure. In the heart, moving from the inside, these layers are the endocardium, myocardium, and epicardium. They correspond to the **tunica intima**, **tunica media** and **tunica externa** of the blood vessels.

### The endocardium

The endocardium is the inner layer of the heart, consisting of the following components:

- **Lamina epithelialis**, composed of a flat single-layer squamous epithelium that provides a low-friction, non-thrombogenic surface.

- **Basal lamina** that anchors the endothelium to the connective tissue.
- **Lamina propria**, the connective tissue layer of the heart containing a network of elastic fibres and smooth muscle cells. The **lamina propria** can further be divided into:
  - **Stratum subendotheliale**
  - **Stratum myoelasticum** (this is the primary component of the heart valves.)
- **Tela subendothelialis**, the layer connected to the myocardium. It contains the muscle fibres that initiate and conduct electrical impulses.

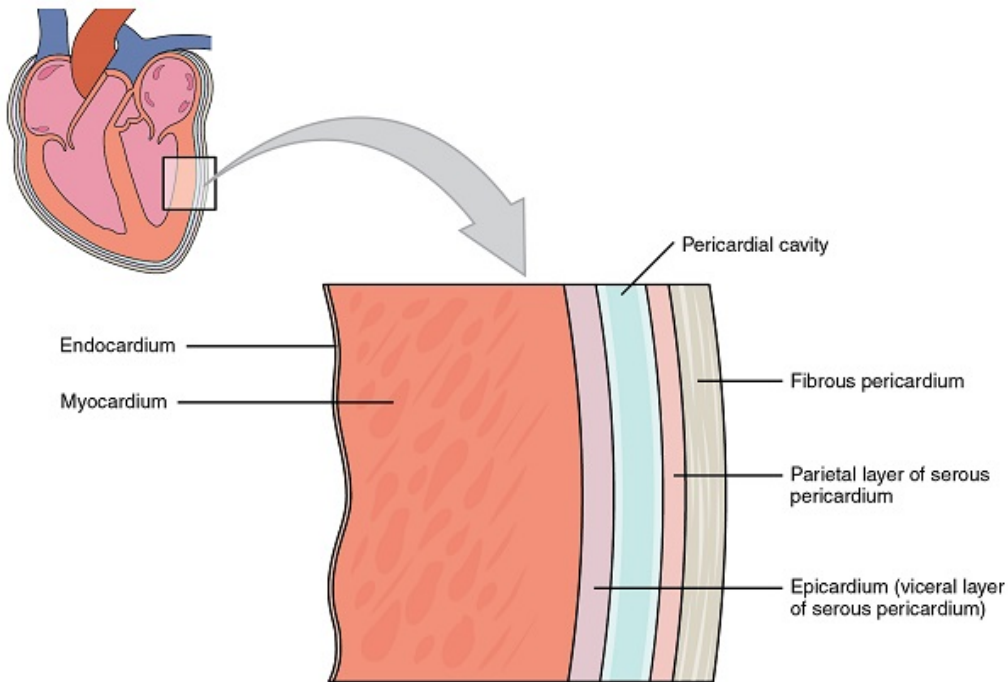


Image: "Pericardial Membranes and Layers of the Heart Wall" by Phil Schatz. License: [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)

### Structure of the heart valves

The heart valves have the same general structure as the endocardium, with the addition of a specialized lamina propria, composed of dense collagenous connective tissue designed to withstand an especially high mechanical load. This specialized endocardium is also known as **valvular endocardium**, and it has the following layers:

- **Lamina epithelialis** (one-layer squamous endothelium)
- **Basal lamina**
- **Lamina propria** (composed of a stratum subendotheliale and a stratum myoelasticum)

The stratum myoelasticum, the specialized tissue layer of the heart valves, is composed of **fibrosa** and **spongiosa**. The fibrosa is a layer of non-vascular, dense collagenous connective tissue. In the atrioventricular valves, it is located on the side facing the ventricles, and in the semilunar valves, on the side facing the arteries. The spongiosa is a layer of loose connective tissue.

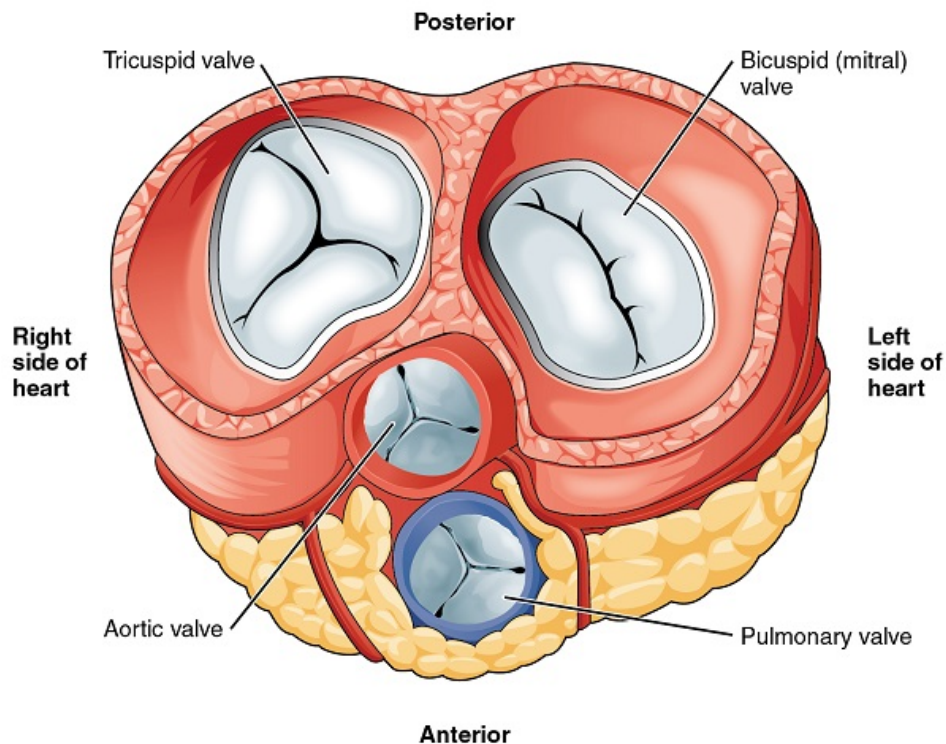


Image: "Heart Valves" by Phil Schatz. License: [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)

### Cardiac skeleton located on the valvular plane

The cardiac skeleton is a structure composed of dense collagenous connective tissue, within which the heart valves are held on a plane. The valves are anchored by four collagenous fibrous rings, the **anuli fibrosi**:

- Anulus fibrosus dexter et sinister (tricuspid and mitral valve)
- Anulus trunci pulmonalis et anulus aortae (pulmonary and aortic valve)

As the valves allow blood flow in only one direction, reference is made to the 'valvular plane' of the heart. The muscle tissue of the atria is almost completely insulated from that of the ventricles by the electrically non-conductive cardiac skeleton. The only structure that conducts impulses through the cardiac skeleton is the bundle of His—part of the specialized muscle cells of the impulse-forming system and the conducting system. This ensures that the ventricles contract after the atria. The collagenous muscle tissue structure of the cardiac skeleton also functions as a firm base and source of the heart musculature.

## Clinical observations

### Endocarditis



Endocarditis is an inflammation of the inner layer of the heart. It is caused by a bacterial infection or an immune system reaction to a streptococcus infection of the tonsillar ring—a secondary infection resulting from rheumatic fever. Endocarditis most frequently occurs in the valve region, especially on the left side of the heart because this region bears a greater mechanical load. Endocarditis caused by substance abuse using infected peripheral venous catheters and injection materials occurs primarily on the tricuspid valve. This happens because the pathogen travels directly via the venous system and enters the right side of the heart.

## The Myocardium

This muscular layer is the thickest of the three heart wall layers. Its thickness is determined by mechanical load, thus it is thinner in the atria than in the ventricles and thicker in the left side of the heart. It is composed of a specialized form of striated muscle—the striated cardiac muscle tissue. Though both cardiac and skeletal striated muscle tissues have similar structures, there are a few key differences.

### **What are the key differences between cardiac and skeletal Muscle?**

The cardiac muscle cells are connected by specialized cell contacts, the **disci intercalares** (intercalated discs). There are three types: **maculae adhaerentes**, **fasciae adhaerentes**, and **gap junctions**.

Skeletal muscle fibers are unbranched, whereas cardiac muscle cells form a three-dimensional network.

Skeletal muscle cells have a peripheral nucleus, whereas cardiac muscle cells have their nucleus located at the center. The oval or rectangular nucleus is extended in the direction of the myofibrils. At both ends of the nucleus is the sarcoplasm that contains glycogen granules, mitochondria, and **lipofuscin**. Lipofuscin is a brown pigment that accumulates in the cells with age.

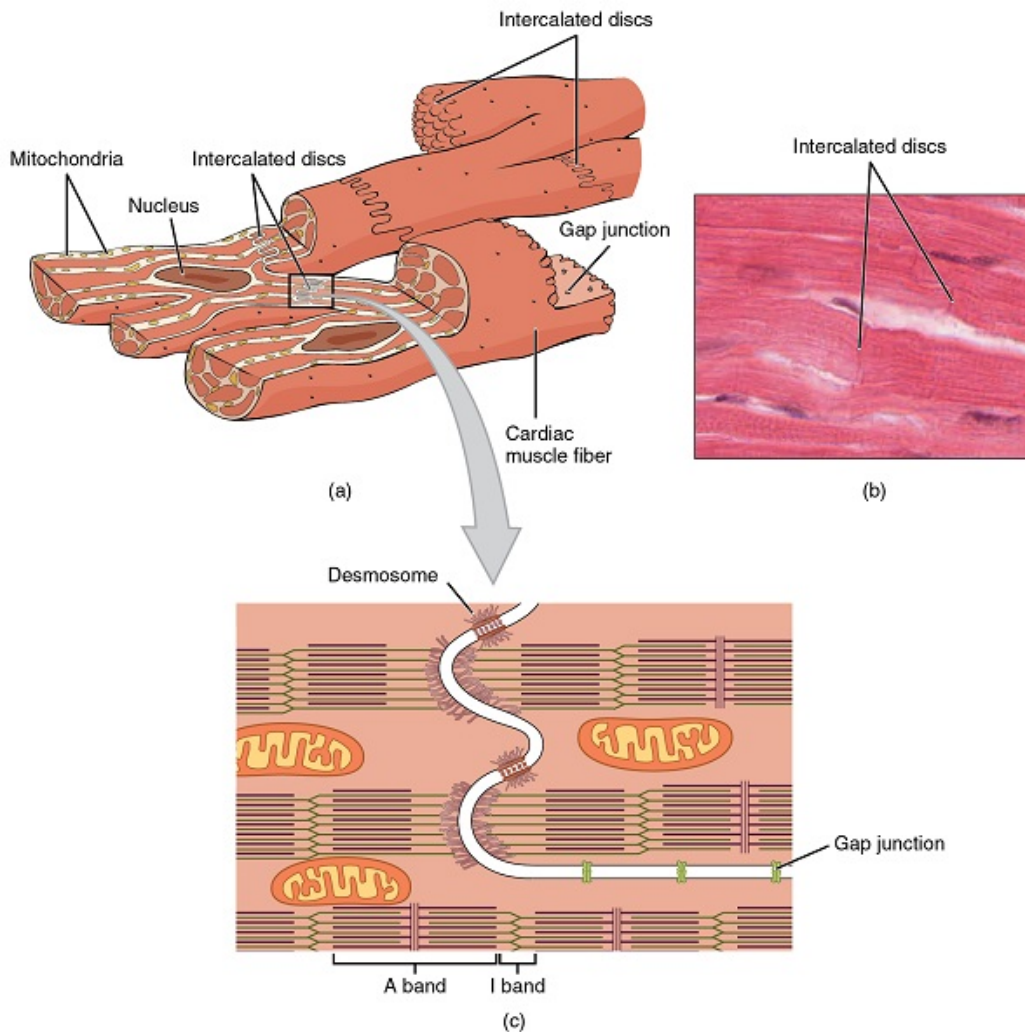


Image: "Cardiac Muscle" by Phil Schatz. License: [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)

### Additional differences between cardiac and skeletal muscle:

Cardiac muscle cells have a basal lamina and a surrounding network of capillaries to support their high metabolic rate. The sarcoplasmic reticulum is less developed than in skeletal muscle. In cardiac muscle cells, the transverse tubules of the sarcolemma (i.e., the T-system) are located next to the Z-lines and form the primary calcium reservoir; the longitudinal system (the L-system) is less pronounced. The T-tubules and L-tubules form a **dyad**. The higher metabolic demands of the cardiac muscle cells result in a smaller diameter and larger quantities of sarcoplasm and mitochondria.

The heart is a specialized part of the blood vessel network, whose function is to pump blood through the circulatory system. Contraction of cardiomyocytes is what underlies the pumping action of the heart. There are two types of cardiomyocytes: the cells of the working musculature, as well as the pacemaker cells that initiate and conduct electrical impulses and function as myoendocrine cells in the regulation of the circulatory function.

## The cardiac working musculature

### Function: contraction of the cardiac muscle

The three layers of the working musculature are oriented in relation to each other in a corkscrew manner. The external longitudinal layer runs from the **cardiac skeleton** to the **Vortex cordis**. The middle layer is composed of circular fiber bundles and is especially

thick in the left ventricle, in order to support a greater pumping force. The inner layer is composed of fibers that radiate from this circular layer, and it includes the **trabeculae carneae** and the **musculi papillares**.

## Clinical observations

### **Cardiac insufficiency**

If the pumping action of the heart is weakened due to a pre-existing condition (e.g., valve defects, heart attack), blood may be retained within a portion of the circulatory system. According to the location, cardiac insufficiency is defined as a right, left or global cardiac insufficiency. Each of these has specific consequences for the human body.

### **Right cardiac insufficiency**

Blood retention in the systemic circulation causes a volume burden on the right heart. Symptoms are engorgement of the neck veins and peripheral edema that is compensated by nocturnal reabsorption, resulting in nocturia.

### **Left cardiac insufficiency**

Blood retention in the pulmonary circulation leads to pressure on the lungs, resulting in pulmonary edema and dyspnoea.

## The specialized cells of the cardiac musculature

### **The pacemaker cells make up the electrical impulse initiation and conduction system.**

Function: the spontaneous, rhythmic initiation and conduction of electrical impulses.

**Note:** The pacemaker cells are cardiac muscle cells, not nerve cells.



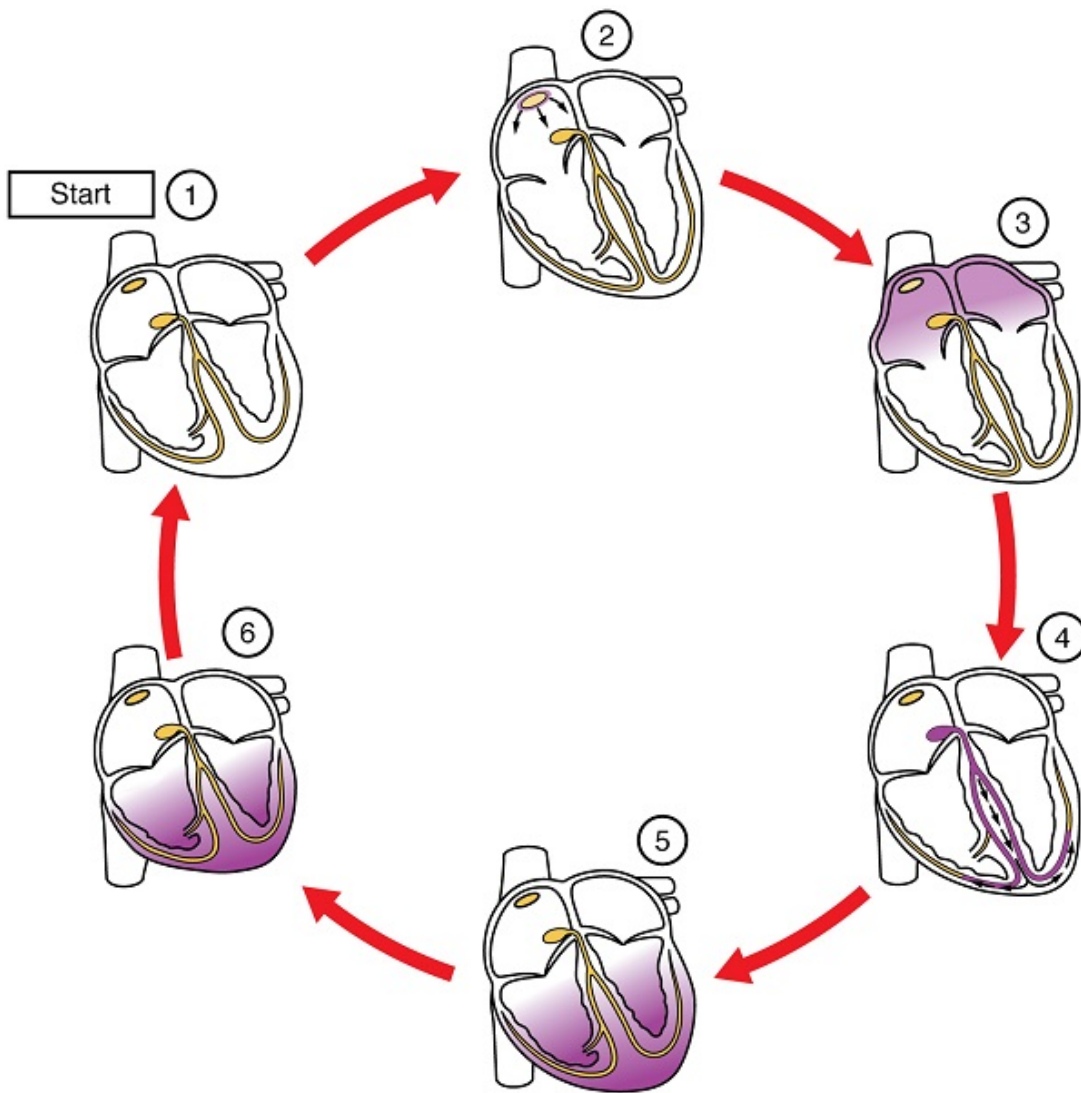


Image: "Cardiac Conduction" by Phil Schatz. License: [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)

The conduction system has several components: the sinoatrial node, the atrioventricular node, the bundle of His, the bundle branch block and the Purkinje fibers. It runs from the right atrium, down through the ventricular septum, to the cardiac apex. It crosses the cardiac skeleton—the collagenous connective tissue layer that separates the atrial and ventricular musculature. The pacemaker components are arranged hierarchically. The sinoatrial node is the primary pacemaker with the highest characteristic frequency. If it malfunctions, the atrioventricular node situated downstream can use its lower characteristic frequency to take over as the primary pacemaker.

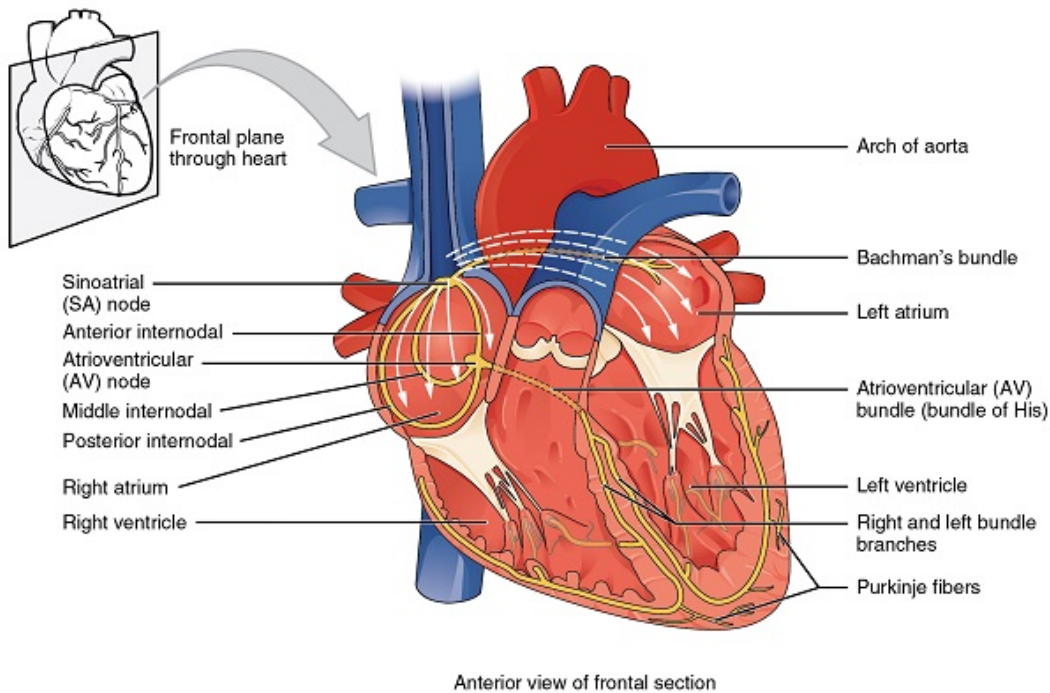


Image: "Conduction System of the Heart" by Phil Schatz. License: [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)

Pacemaker cells have a high quantity of glycogen and few myofibrils and are larger than the cells of the working musculature.

### The myoendocrine cells

Function: endocrine regulation of the circulatory system.

### ANP

**Atrial natriuretic peptide (ANP)**, otherwise known as **cardiodilatin**, is secreted in the cardiac cells of the atrial auricles. This peptide hormone prevents cardiac overload through two mechanisms:

1. ANP causes a reduction in blood volume by signaling the kidneys to reabsorb less NaCl. NaCl is excreted along with water, causing increased **diuresis**.
2. ANP stimulates vasodilation of the blood vessel walls, reducing peripheral vascular resistance.

Secretion of ANP is stimulated by increased stretching of the right atrium (e.g., due to cardiac insufficiency) or when activated by the sympathetic nervous system.

### BNP

BNP (brain natriuretic peptide) is produced by cardiomyocytes in the ventricles. Secretion is stimulated mainly by increased ventricular stretching (e.g. due to cardiac insufficiency). BNP and ANP have an antifibrotic and antihypertrophic effect on the heart.

## Clinical observations

### Cardiac muscle hypertrophy

Cardiac muscle hypertrophy describes an increase in cardiac muscle mass. It is caused by the enlargement of cardiomyocytes as a reaction to chronic overload. This is caused either physiologically (additional loading is the desired outcome of high-performance



sport), or pathologically, by increased ventricular pressure or volume load.

## The Epicardium

Epicardium = pericardium serosum, visceral lobe

The epicardium is the visceral lobe of the **pericardium serosum** that firmly adheres to the heart, forming part of the pericardial sac. Like all other serous membranes, it is composed of:

- Tunica serosa—serosa epithelium, composed of single-layer squamous mesothelium
- Lamina propria—serosa connective tissue with numerous elastic fibers, along with blood and lymph vessels
- Tela subserosa—a sliding layer whose adipose tissue cushions the surface of the heart and envelopes the coronary vessels in the sulci.

Both the outer and inner surfaces of the heart are low-friction and elastic, perfectly suited to the high mechanical load on an active heart.

## The Pericardium

The pericardium is the connective tissue surrounding the heart. It has two components:

1. Pericardium serosum (serous epicardial membrane = visceral lobe and parietal lobe)
2. Pericardium fibrosum

The richly vascularised tela subpericardialis is situated between these layers.

## The pericardium serosum

The pericardium serosum is the serous membrane surrounding the heart. Like all serous membranes, it has two serous lobes:

- Lamina visceralis = Epicardium (the outer layer of the cardiac wall)
- Lamina parietalis, which firmly adheres to the Pericardium fibrosum.

Both lobes merge at a reflecting fold to form the **cavitas pericardica** or pericardial cavity. This capillary-rich space is filled with a few milliliters of serous fluid, an ultrafiltrate from the blood. It allows low-friction sliding movements of the organs.

## The pericardium fibrosum

The collagenous pericardium fibrosum reinforces the lamina parietalis. This layer has very little elasticity.

The reflecting folds of the serous lobes (mesocardium) form the following sinuses:

- Sinus transversus pericardii
- Sinus obliquus pericardii

In addition, the heart is attached to its surroundings via the following structures:

- Ligamenta phrenicopericardiaca
- Membrana bronchopericardiaca

- Ligamenta sternopericardiaca

## Lymphatic Vessels

### Components of the CVS

#### **Anatomy**

- Lymph nodes scattered throughout the body (thymus, spleen)
- Vessels

#### **Functions**

- Returns excess body fluid to the blood
- Transports fats from intestines to blood
- Defense

### Main classes of blood vessels

#### **Arteries**

- Convey blood away from the heart to the body tissues
- Bifurcate into smaller vessels (arterioles) as they get further from the heart until they feed into the capillaries

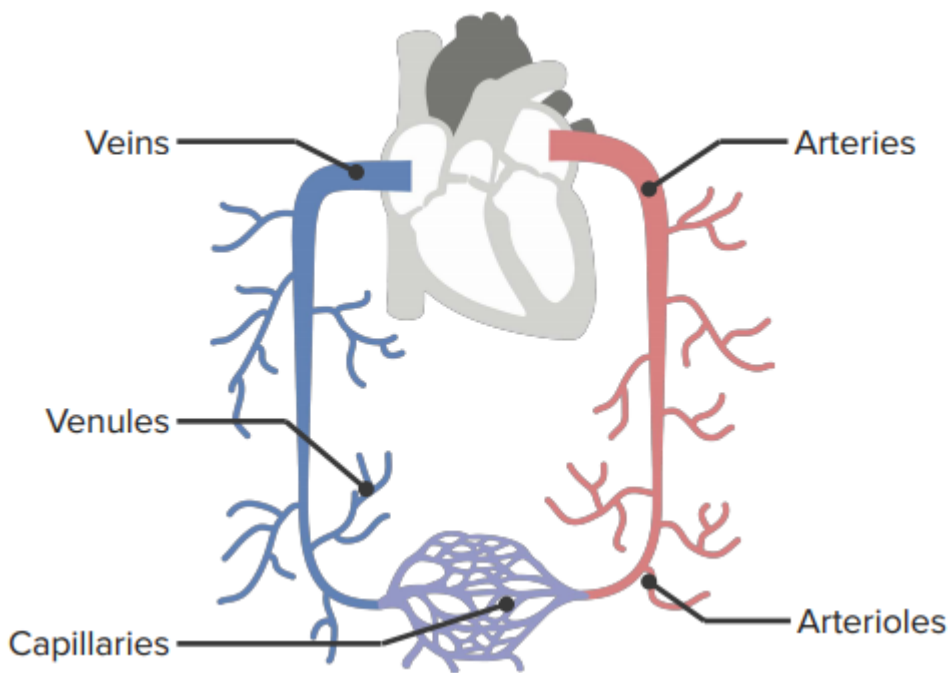
#### **Capillaries**

- Exchange oxygen, carbon dioxide, nutrients, and waste products

#### **Veins**

- Return blood to the heart
- Become progressively smaller as they split and get further away from the heart (venules)

### Components of the CVS



## Main classes of blood vessels

### Anastomosis

- Happens where two or more vessels merge to supply the same body region.
- Veins tend to form many more anastomoses than arteries do.

## Diseases of the Heart

### Pericardial effusion



Image: "CT Pericardial effusion" by James Heilman, MD. License: [CC BY-SA 3.0](https://creativecommons.org/licenses/by-sa/3.0/)

Pericardial effusion is the accumulation of fluid in the pericardium. This condition can have a variety of causes:

### Hemic effusion

- A heart attack can cause extensive necrosis of the cardiac wall. This forms weak points that can rupture and cause hemorrhaging into the pericardium.
- Ruptured aneurysm of the aorta ascendens
- Hemorrhagic diathesis
- Physical trauma

## Serous effusion

- Transudate due to right cardiac insufficiency or **hypoalbuminemia**.

## Effusion caused by a viral infection

- e.g., **coxsackie-virus**

## Purulent effusion = empyema

- during the course of sepsis;
- when the infection spreads from the surrounding structures to the heart.

## Pericardial tamponade

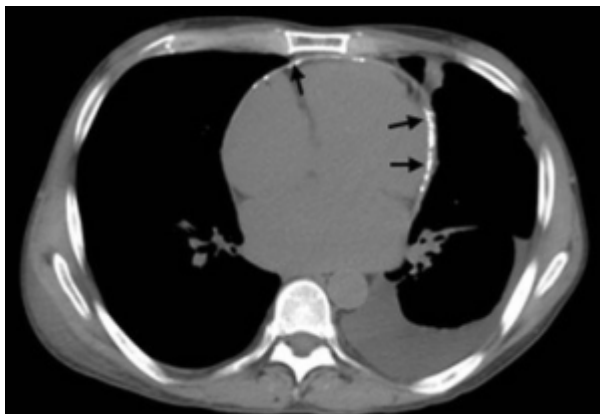
Pericardial effusion leads to increased pressure on the pericardial cavity and afferent veins, causing incomplete filling of the heart during diastole. Blood ejection during systole is decreased, causing a fall in blood pressure and shock.

## Pericarditis

Causes of infection of the pericardial sac include:

- Viral, bacterial or fungal infection; can also occur via spreading from surrounding structures (e.g., pneumonia)
- Uremic pericarditis caused by chronic kidney infection
- Tuberculosis
- Tumor
- Irradiation of the thorax
- Autoimmune disorders such as **SLE** (systemic lupus erythematosus);
- Post-traumatic consequence of a heart attack or as **Dressler syndrome** following surgery.

## Pericarditis calcarea



[Image](#): "Chylous ascites and chylothorax due to constrictive pericarditis in a patient infected with HIV: a case report" by Summachiwakij S, Tungsubutra W, Koomanachai P, Charoenratanakul S . License: [CC BY 2.0](#)

Pericarditis calcarea is caused by reoccurring inflammation of the pericardium. This leads to tissue scarring and calcification, preventing the flexible, low-friction gliding of the pericardial lobes. The heart can no longer completely dilate during the filling phase, causing venous blood retention and the resultant visible internal and external symptoms.

It also leads to consequent secondary diseases. Surgical intervention is required.

## Review Questions

The answers are below the references.

### 1. The cardiac musculature...

- A. ... resembles the skeletal musculature in structure.
- B. ... has cells with a peripheral nucleus.
- C. ... is composed of unbranched fibers.
- D. ... is composed of cardiomyocytes with a low amount of mitochondria and sarcoplasm.
- E. ... also has an endocrine function.

### 2. The heart valves...

- A. ... are composed of specialized muscle cells.
- B. ... have no stratum myoelasticum.
- C. ... are an extension of the endocardium.
- D. ... are, in comparison to other cardiac structures, seldom affected by inflammation.
- E. ... are attached to the pericardium by connective tissue.

### 3. Pericarditis...

- A. ... is an inflammation of the inner surface of the heart.
- B. ... can lead to heart valve insufficiency.
- C. ... is another term for pericarditis calcarea.
- D. ... can be caused by chronic kidney disease.
- E. ... is a secondary disease caused by streptococcus infections.

## References

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**Correct answers:** 1E, 2C, 3D

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