# Cardiovascular anatomy physiology

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http://sinoemedicalassociation.org/AP2/

# The Cardiovascular System: The Heart

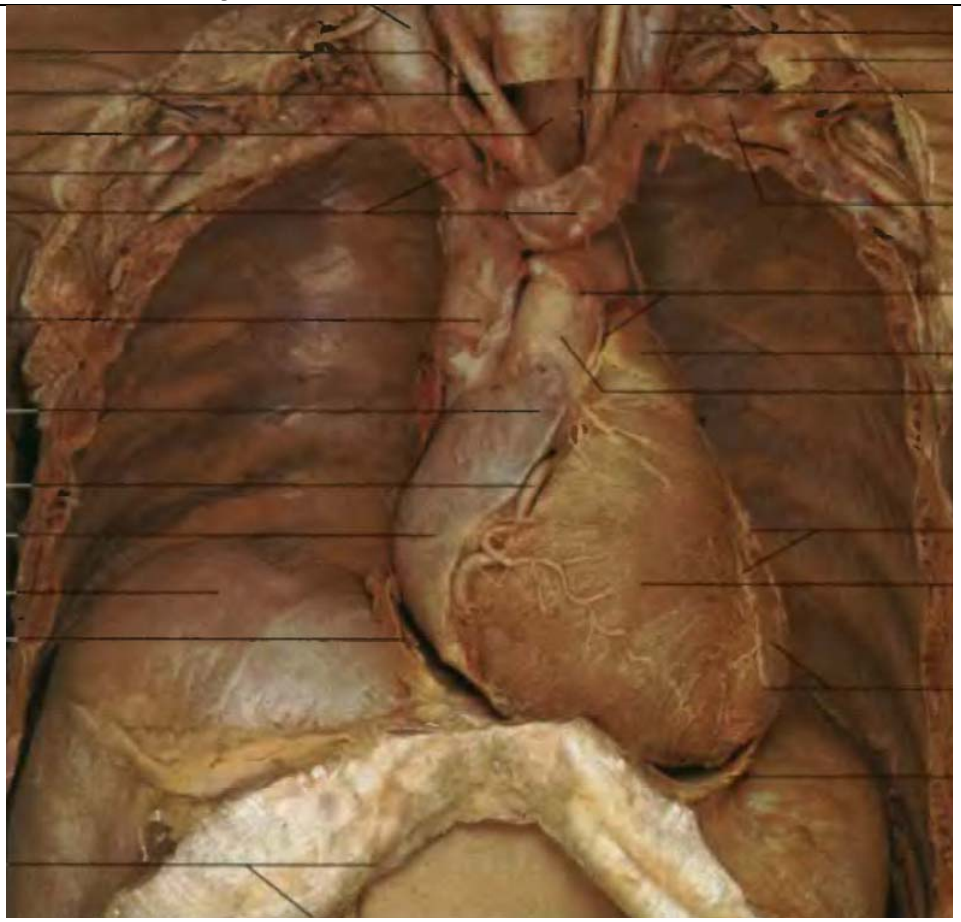
In the embryo, the heart begins to beat at 4 weeks of age, even before its nerve supply has been established.
If a person lives to be 80 years old, his or her heart continues to beat an average of 100,000 times a day, every day for each of those 80 years. Imagine trying to
squeeze a tennis ball 70 times a minute. After a few minutes, your arm muscles would begin to tire.

Then imagine increasing your squeezing rate to 120 times a minute.

Most of us could not keep that up very long, but that is what the heart does during exercise.

A healthy heart can increase its rate and force of contraction to meet the body's need for more oxygen, then return to its resting rate and keep on beating as if nothing very extraordinary had happened.

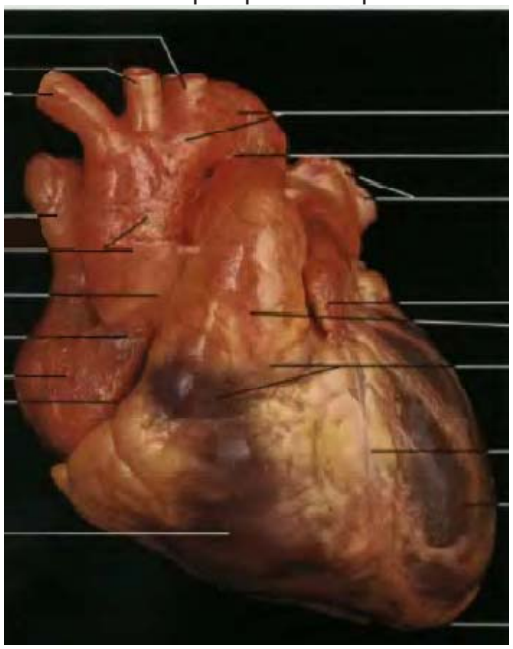
In fact, it isn't extraordinary at all; this is the job the heart is meant to do.

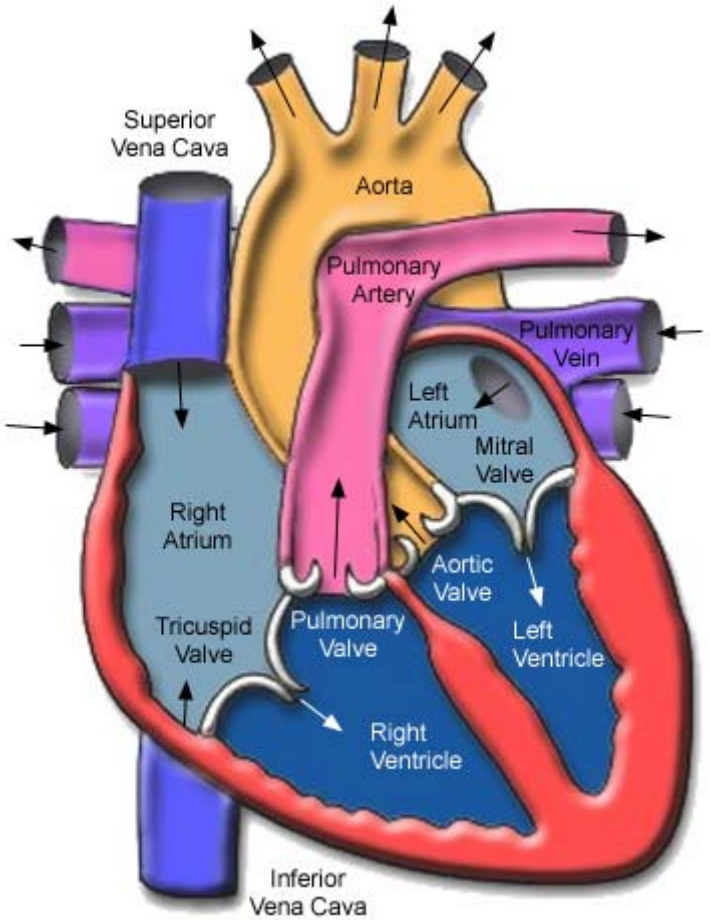


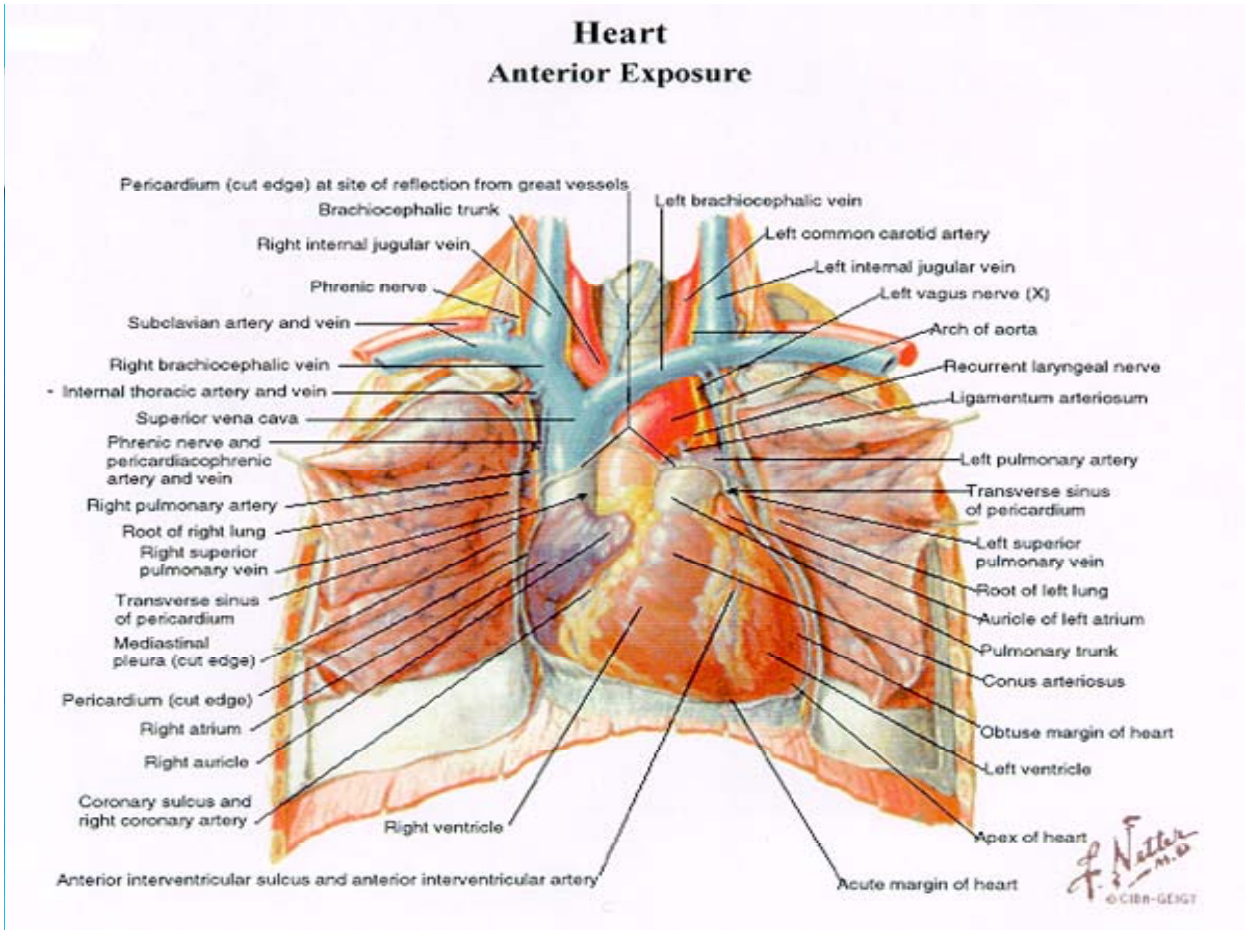
The primary function of the heart is to pump blood through the arteries, capillaries, and veins.

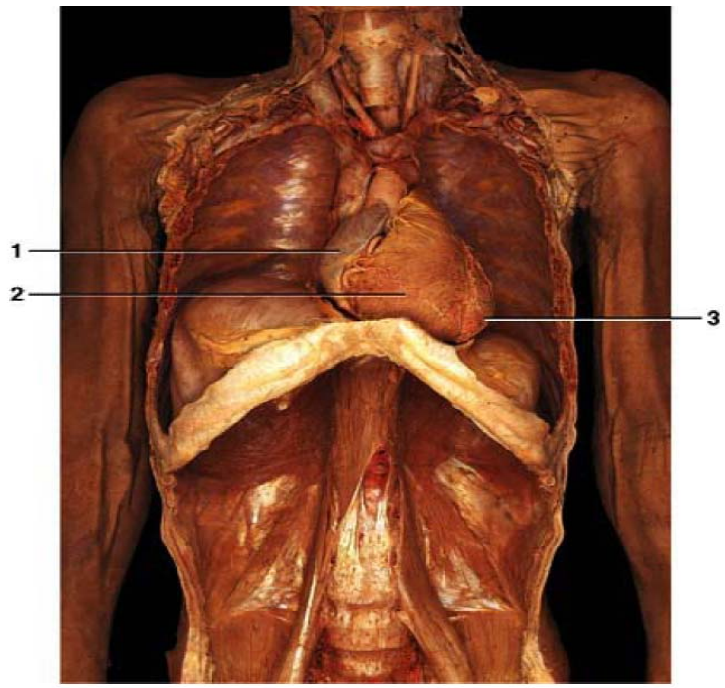
As you learned in the previous chapter, blood transports oxygen and nutrients and has other important functions as well.

The heart is the pump that keeps blood circulating properly.








## *1.5*

1. **right atrium**; forms right border of heart
2. **right ventricle**; forms most of sternocostal surface of heart
3. **left ventricle**; forms most of left border of heart

# Heart Anatomy

- Approximately the size of your fist
- Location
  - ***Superior surface of diaphragm***
  - ***Left of the midline***
  - ***Anterior to the vertebral column, posterior to the sternum***
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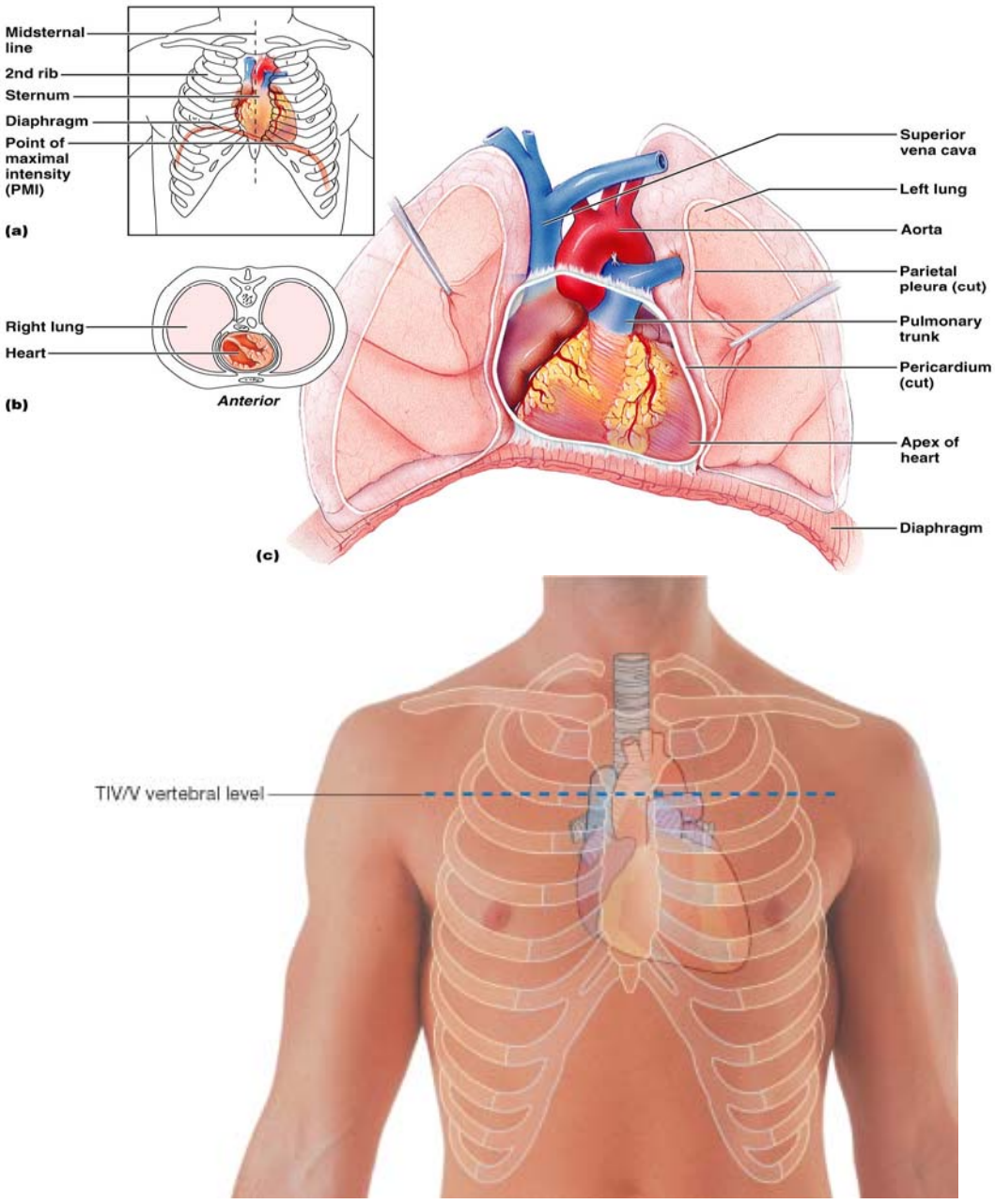



The **heart** is positioned obliquely between the lungs in the mediastinum

▪It rests on the superior surface of the diaphragm, medial to the lungs, anterior to the esophagus and vertebral column, and posterior to the sternum. Its **base** is directed toward the right shoulder

- Its **apex** points to the left hip.

About twothirds of its bulk lies to the left side of the midline of the body.

It is shaped like a blunt cone. It is about the size of a closed fist. It is approximately 5 inches long (12 cm), 3.5 inches wide at its broadest point (9 cm), and 2.5 inches thick (6 cm).

It is enclosed in a loose fitting serous membrane known as the **pericardial sac,** which can also be referred to as the parietal pericardium.

**Orientation of the Heart**

The heart and roots of the great vessels within the pericardial sac are related anteriorly to the sternum, costal cartilages, and the medial ends of the 3rdâ€“5th ribs on the left side. The heart and pericardial sac are situated obliquely, about two thirds to the left and one third to the right of the median plane. The heart is shaped like a tippedover, three-sided pyramid with an apex, base, and four surfaces.

The **apex of the heart**

Is directed anteriorly and to the left and is formed by the inferolateral part of the left ventricle.
Is located posterior to the left 5th intercostal space in adults, usually 9 cm from the median plane.
Is where the sounds of mitral valve closure are maximal (**apex beat**); the apex underlies the site where the

The **base of the heart**

Is the heart's posterior aspect.
Is formed mainly by the left atrium, with a lesser contribution by the right atrium.
Faces posteriorly toward the bodies of vertebrae T6â€“T9, and is separated from them by the pericardium, oblique pericardial sinus, esophagus, and aorta.

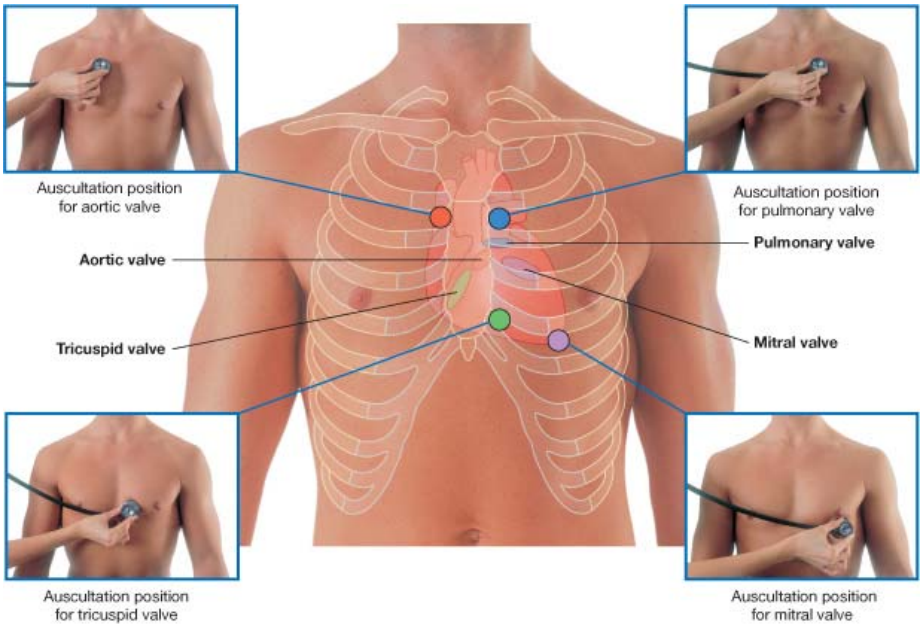
Extends superiorly to the bifurcation of the pulmonary trunk and inferiorly to the coronary groove.
Receives the pulmonary veins on the right and left sides of its left atrial portion and the superior and inferior venae cavae at the superior and inferior ends of its right atrial portion.

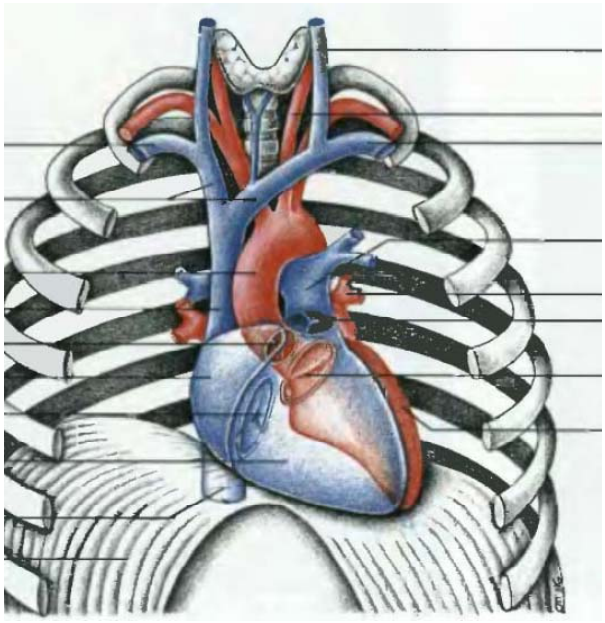
The **four surfaces of the heart** are the

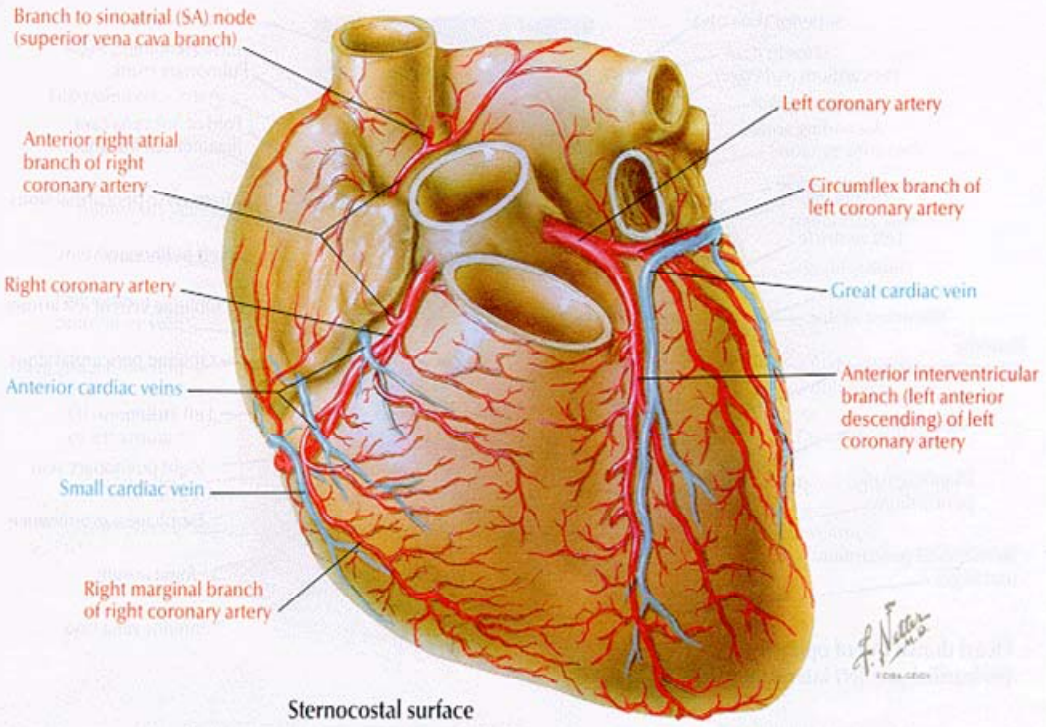
- **Anterior (sternocostal) surface**, formed mainly by the right ventricle.
- **Diaphragmatic (inferior) surface**, formed mainly by the left ventricle and partly by the right ventricle; it is
- related to the central tendon of the diaphragm.
- **Left pulmonary surface**, formed mainly by the left ventricle; it forms the cardiac impression of the left lung.
- **Right pulmonary surface**, formed mainly by the right atrium.

The heart appears trapezoidal in both anterior and posterior views.
The **four borders of the heart** are the

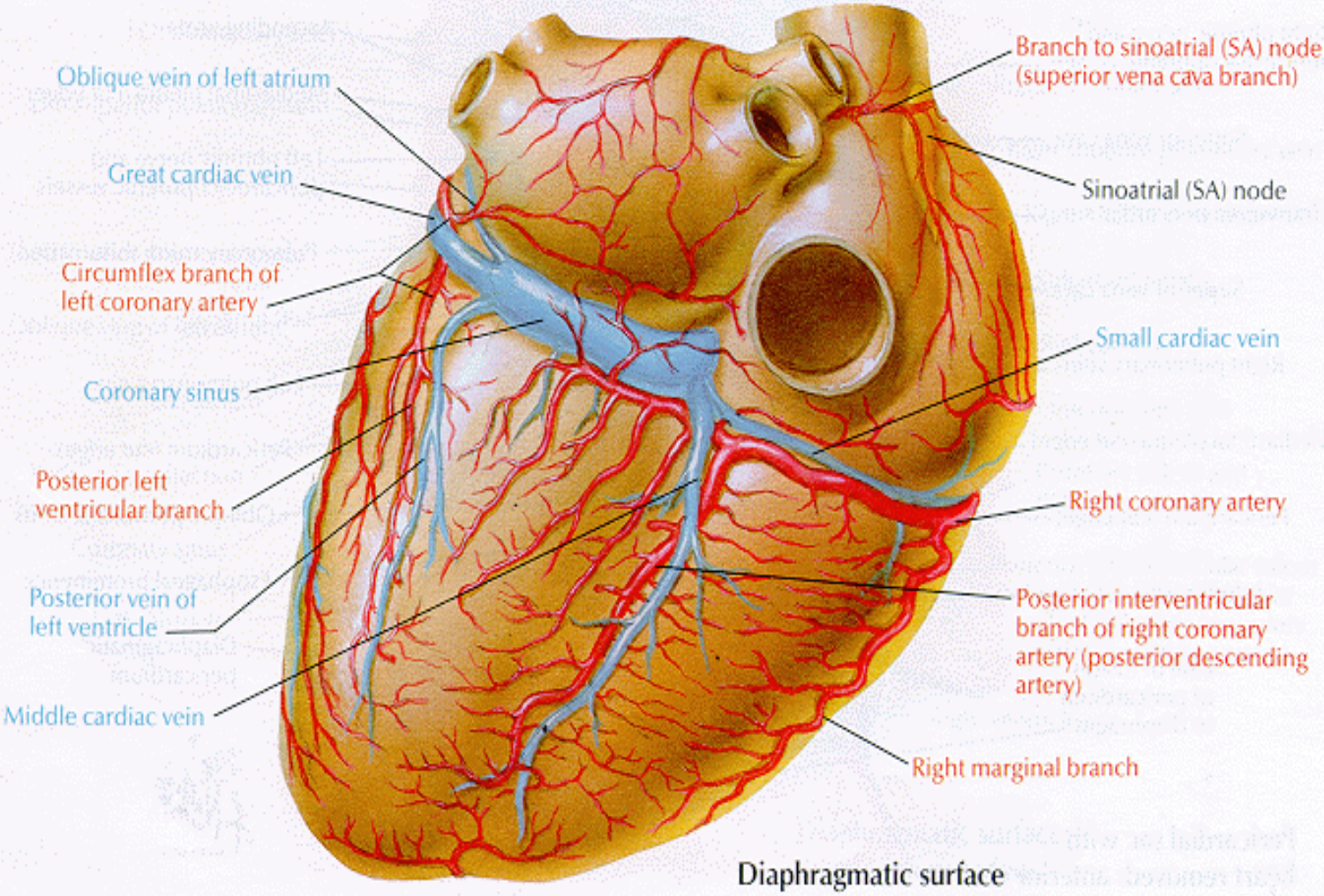
- **Right border** (slightly convex), formed by the right atrium and extending between the SVC and the IVC.
- **Inferior border** (nearly horizontal), formed mainly by the right ventricle and only slightly by the left ventricle.
- **Left border** (oblique), formed mainly by the left ventricle and slightly by the left auricle.
- **Superior border**, formed by the right and left atria and auricles in an anterior view; the ascending aorta and pulmonary trunk emerge from the superior border, and the SVC enters its right side. Posterior to the aorta and pulmonary trunk and anterior to the SVC, the superior border forms the inferior boundary of the transverse
- pericardial sinus.






Sternocostal surface




Diaphragmatic surface

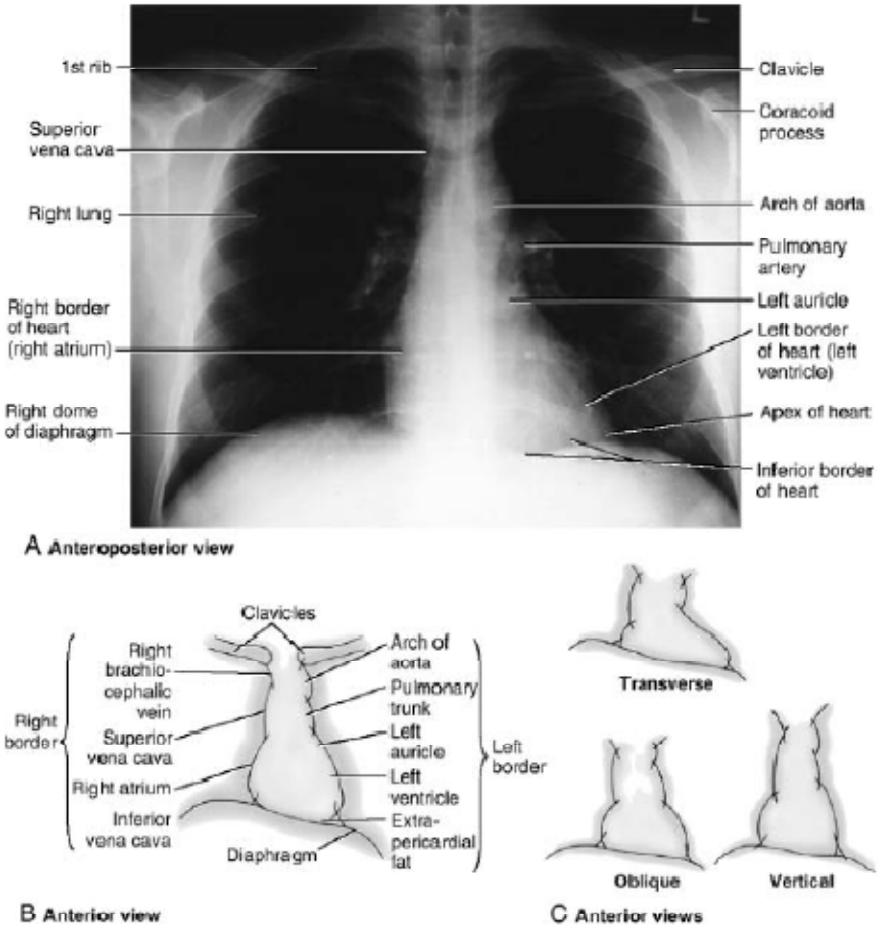



**Figure 1.26. Radiograph and cardiovascular shadows. A.** A radiograph of the heart is shown. **B.** The composition of the margins of the cardiovascular shadow (cardiac silhouette) are identified. **C.** Common types of cardiovascular shadows are defined.

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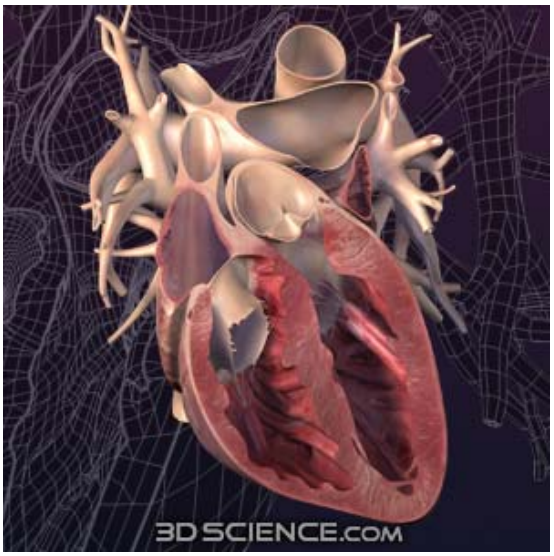
**Pericardium** –

A double-walled sac around the heart composed of:

- A superficial fibrous pericardium
- A deep two-layer serous pericardium
  - The parietal layer lines the internal surface of the fibrous pericardium
  - The visceral layer or epicardium lines the surface of the heart
  - They are separated by the fluid-filled pericardial cavity

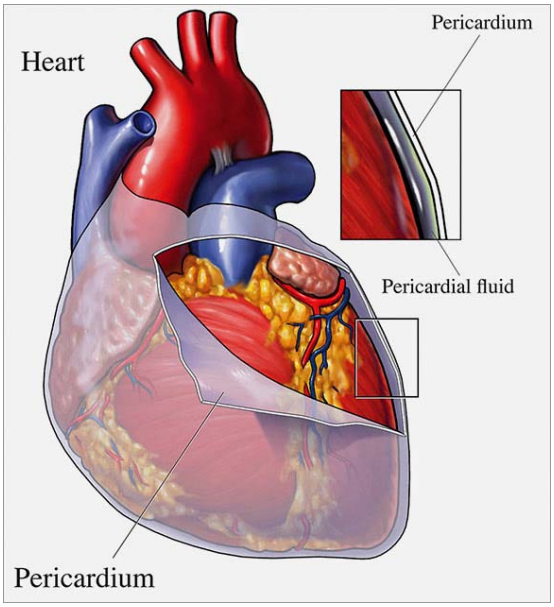
- The superficial layer is the **fibrous pericardium** – a collagenous structure that anchors the heart and prevents its over distention.
- Deeper is the **serous pericardium**, a 2 layered serous membrane.
- The **parietal pericardium** is the outer of the 2 and lines the inner surface of fibrous pericardium.
- The **visceral pericardium** is the inner of the 2 and is also the external covering of the heart. It is a.k.a. the **epicardium**.
- The parietal and visceral layers are continuous with one another where the great vessels leave the heart.
- The **pericardial cavity** is the potential space btwn the parietal and visceral layers. It contains serous fluid, which reduces friction.

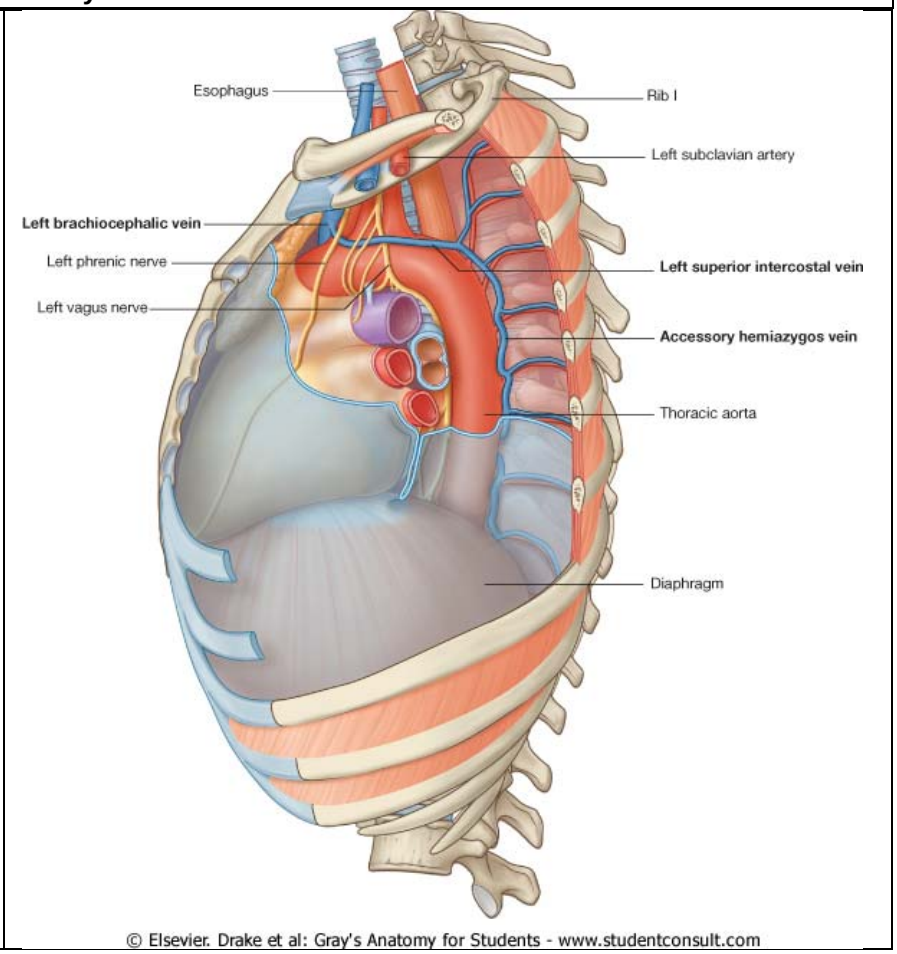
- The pericardium:
  - Protects and anchors the heart
  - Prevents overfilling of the heart with blood
  - Allows for the heart to work in a relatively friction-free environment

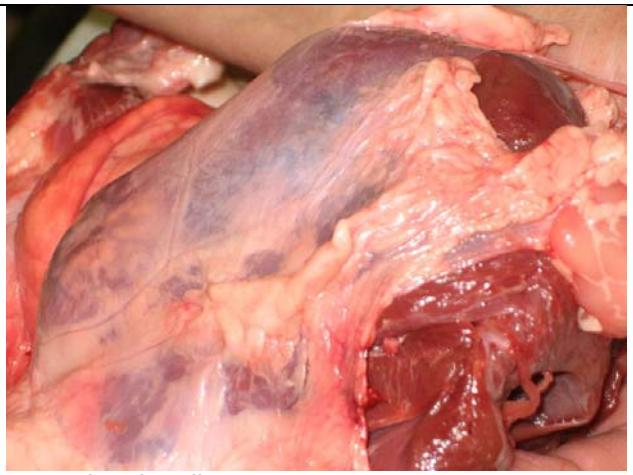



**Pericardial Layers of the Heart**

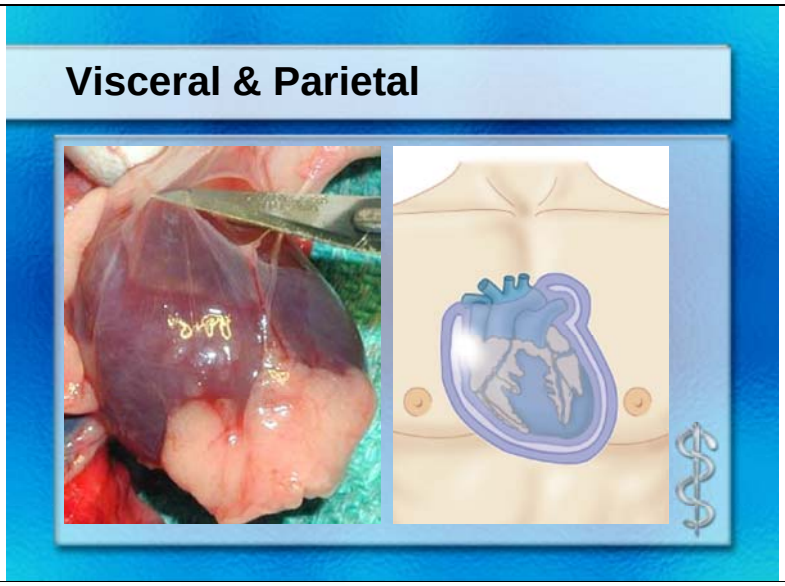
**The pericardium is subdivided into visceral and parietal pericardium.**
**Visceral layer is the outer layer of the heart itself (epicardium)**
**Parietal layer lines the inner portion of the pericardial sac and is deep to a meshwork of collagen fibers that stabilize the position of the heart.**

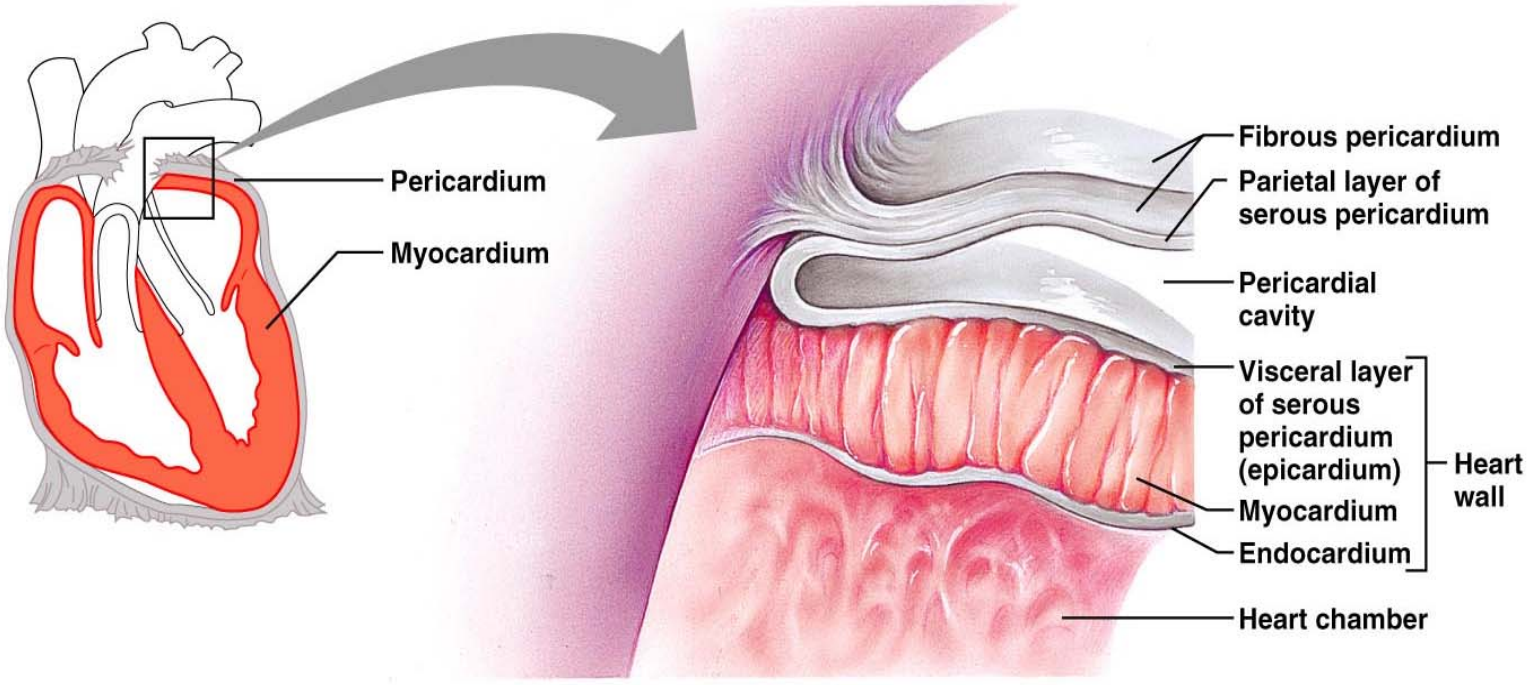




Serosal pericardium




# Heart Wall

- **Epicardium** – visceral layer of the serous pericardium
- **Myocardium** – cardiac muscle layer forming the bulk of the heart
- **Fibrous skeleton of the heart** – crisscrossing, interlacing layer of connective tissue
- **Endocardium** – endothelial layer of the inner myocardial surface

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Like arteries, the heart is lined with **endothelial cells**.

This endothelial layer is known as the **endocardium**.

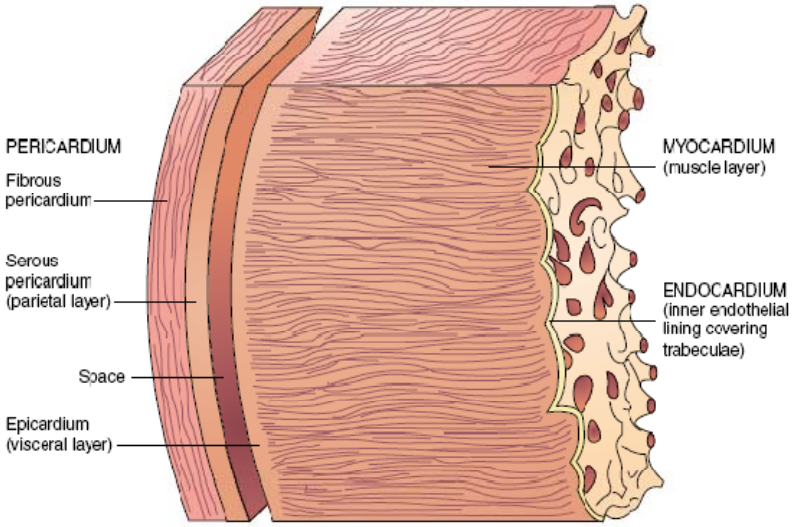
The cardiac muscle above these endothelial cells is known as the **myocardium**.

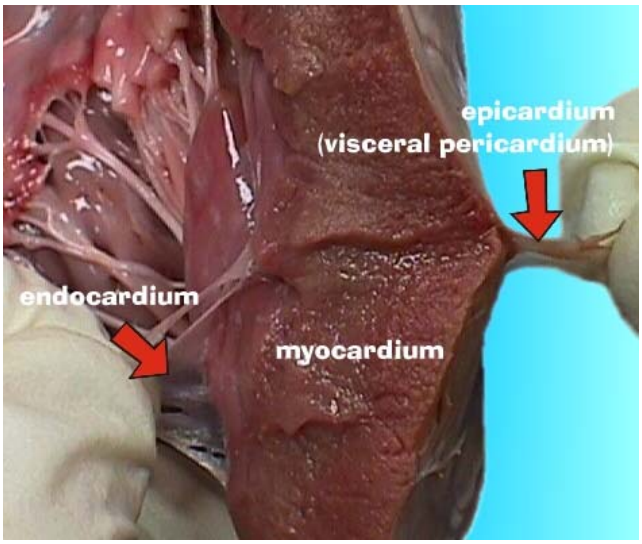
Cardiac muscle cells are specialized elongated striated muscle cells containing centrally placed nuclei.

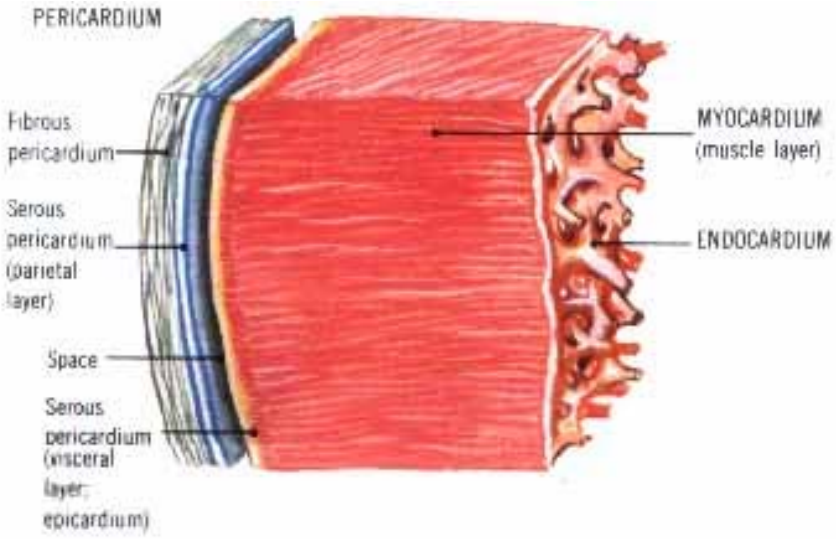
Their appearance varies depending on whether the muscle cells are cut in longitudinal or transverse section.

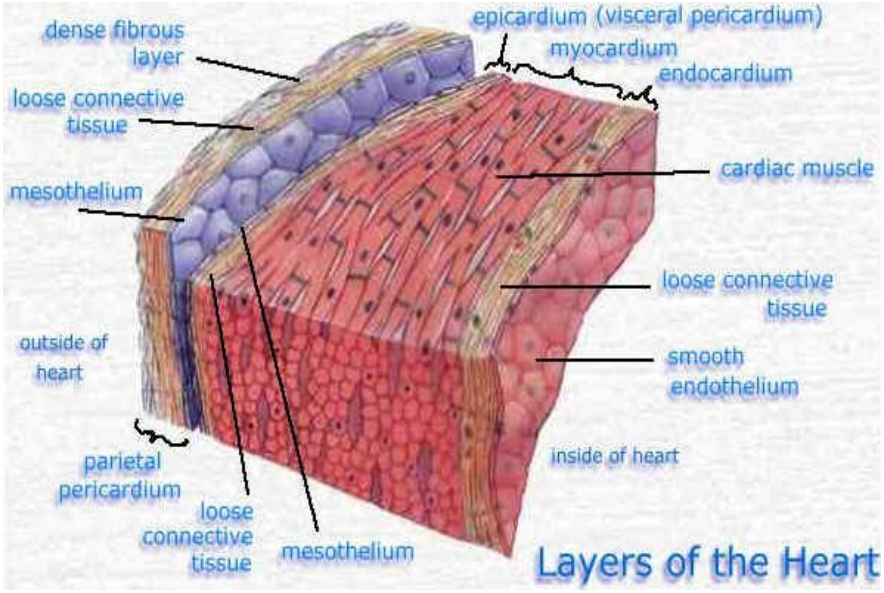
The myocardium is surrounded by a layer of connective tissue known as the **epicardium** (analogous to the tunica adventia of blood vessels).

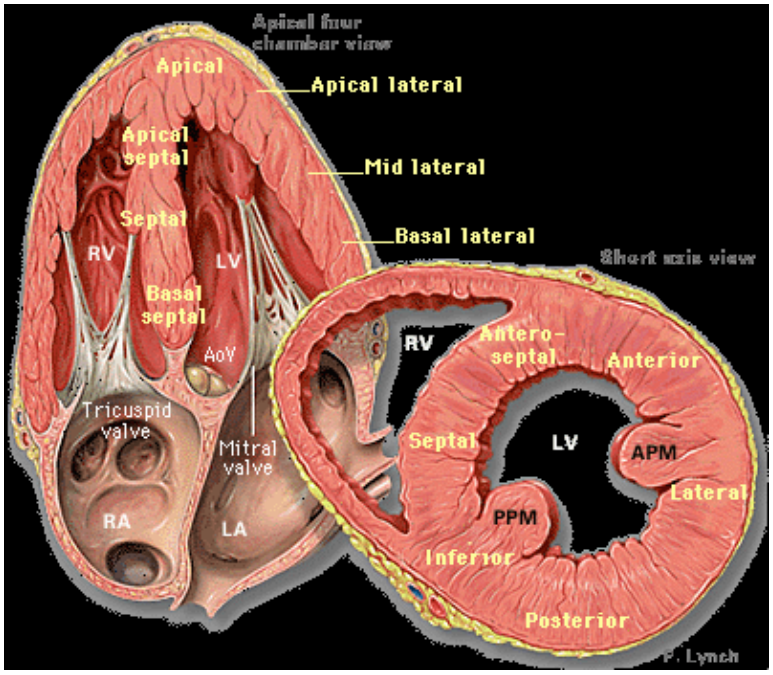
The epicardium is covered with a layer of a lubricated membrane known as the **pericardium**.



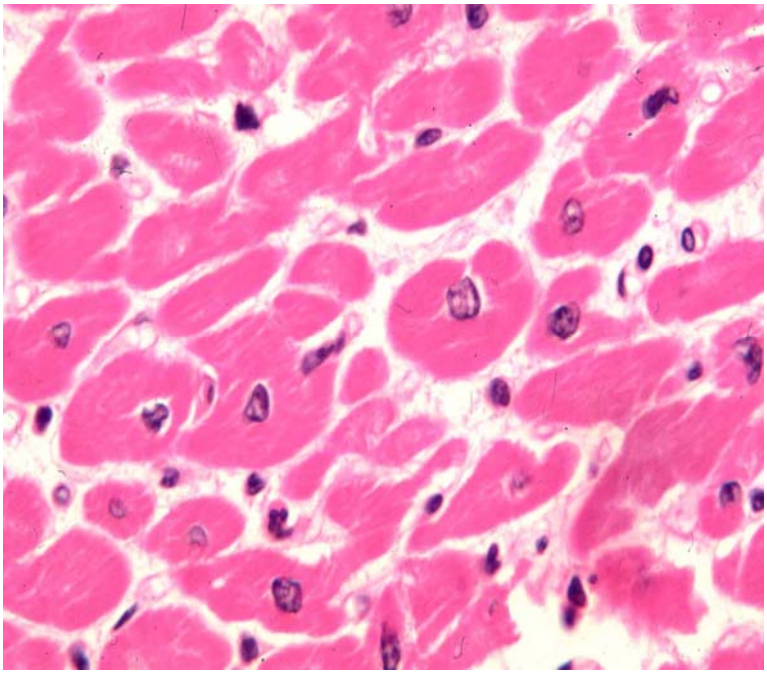



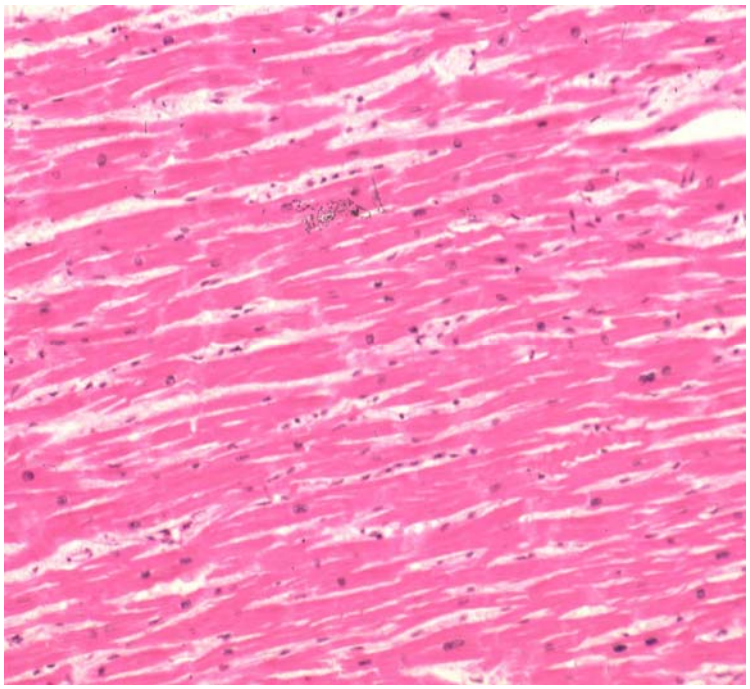



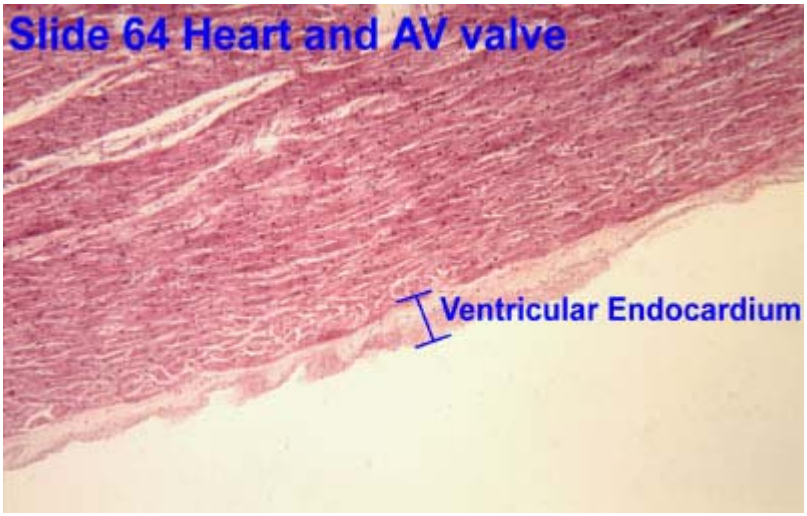


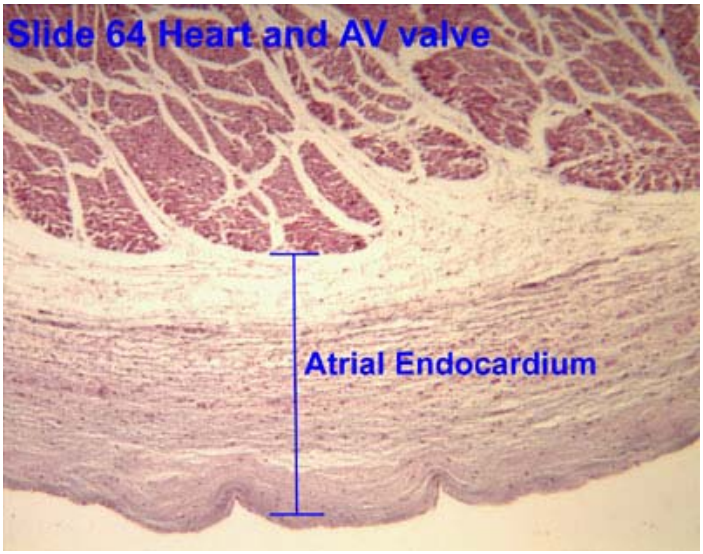

MYOCARDIUM

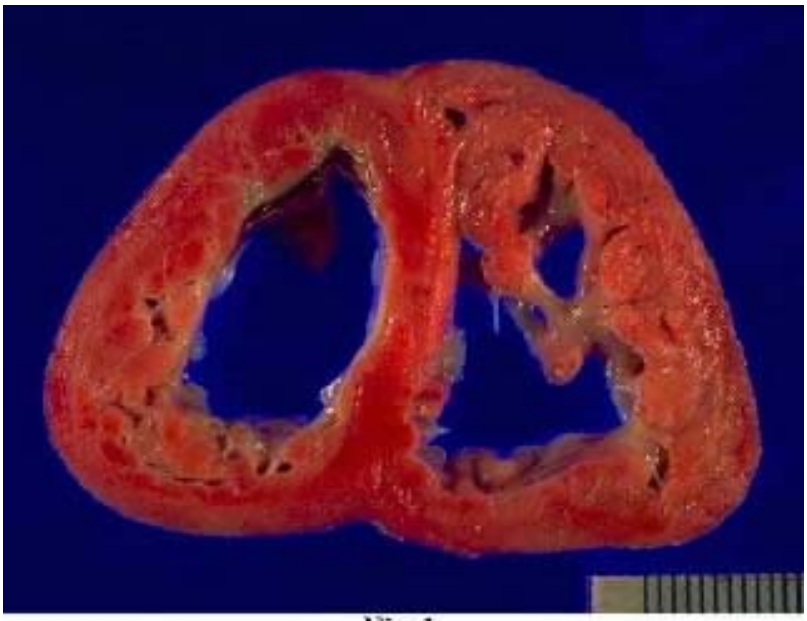




ENDOCARDIUM

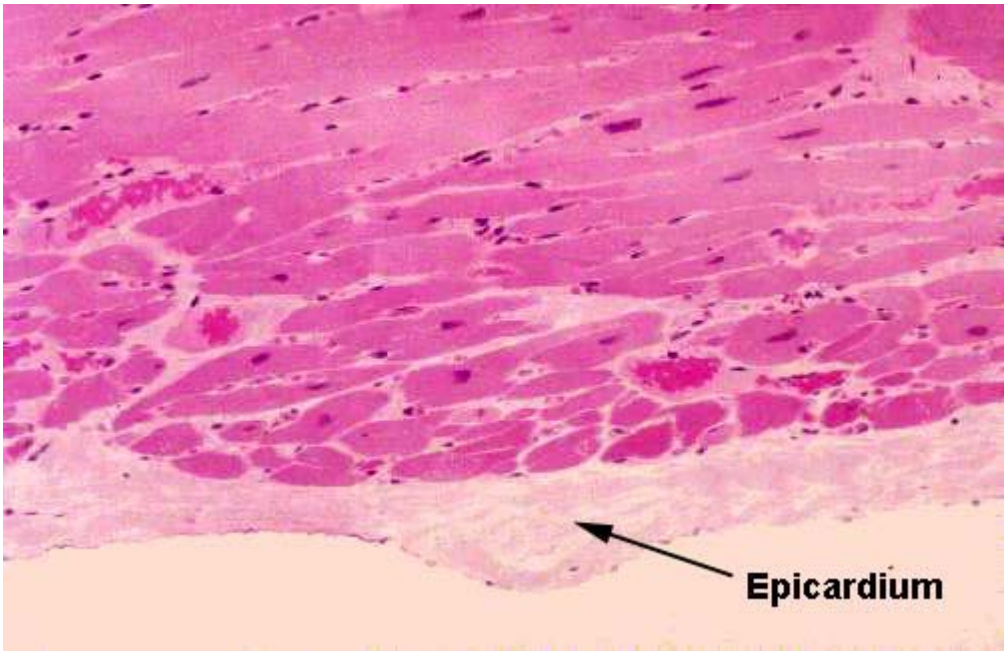


-Fig.1-

EPICARDIUM



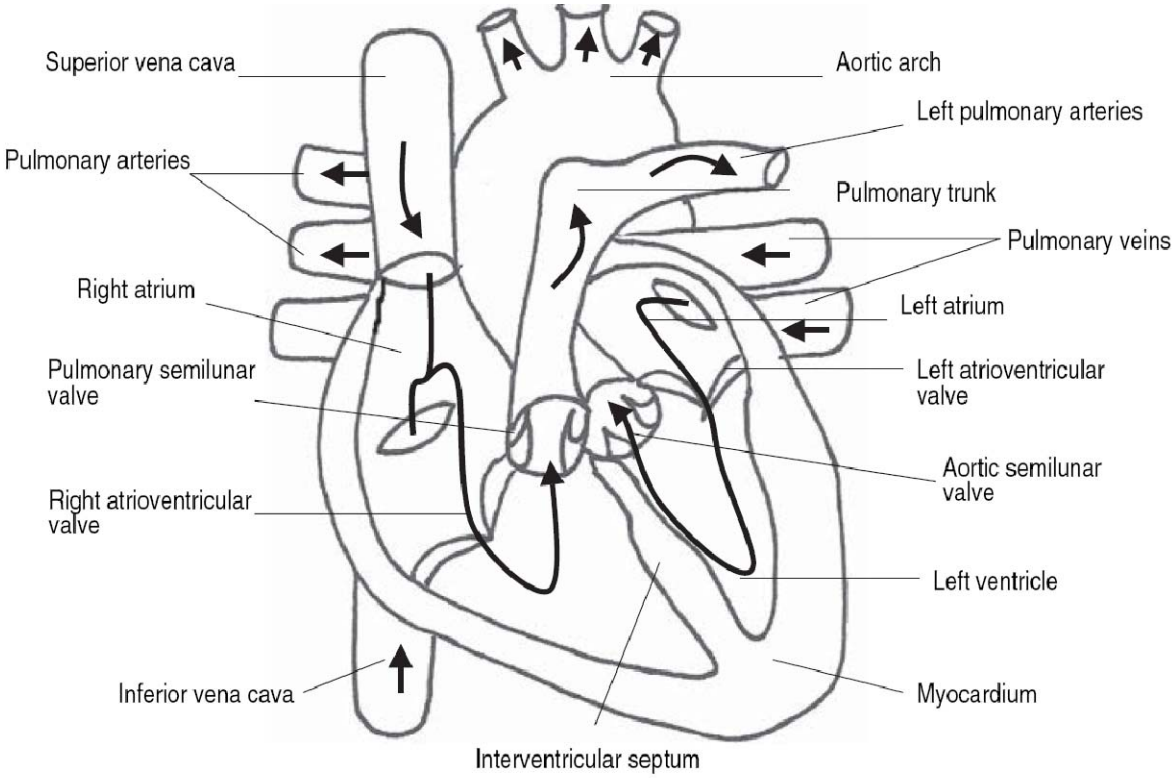
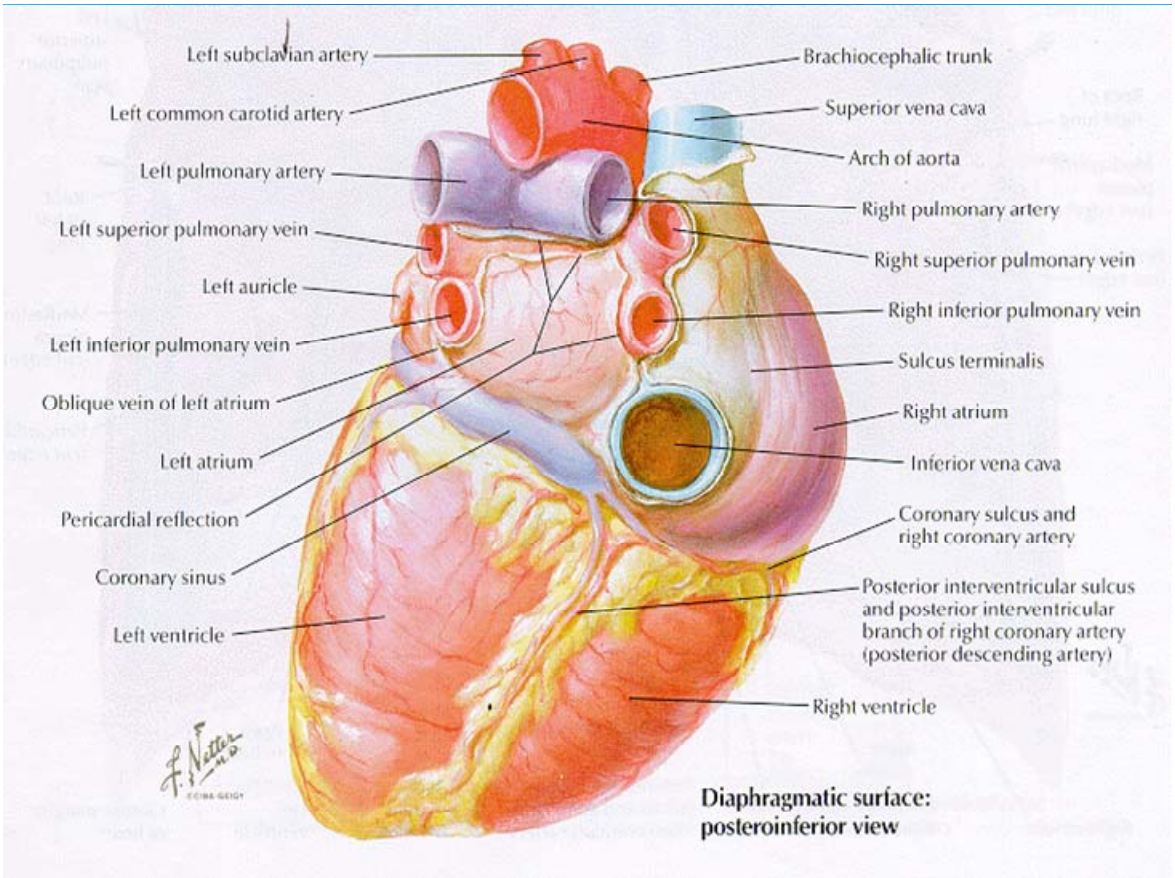
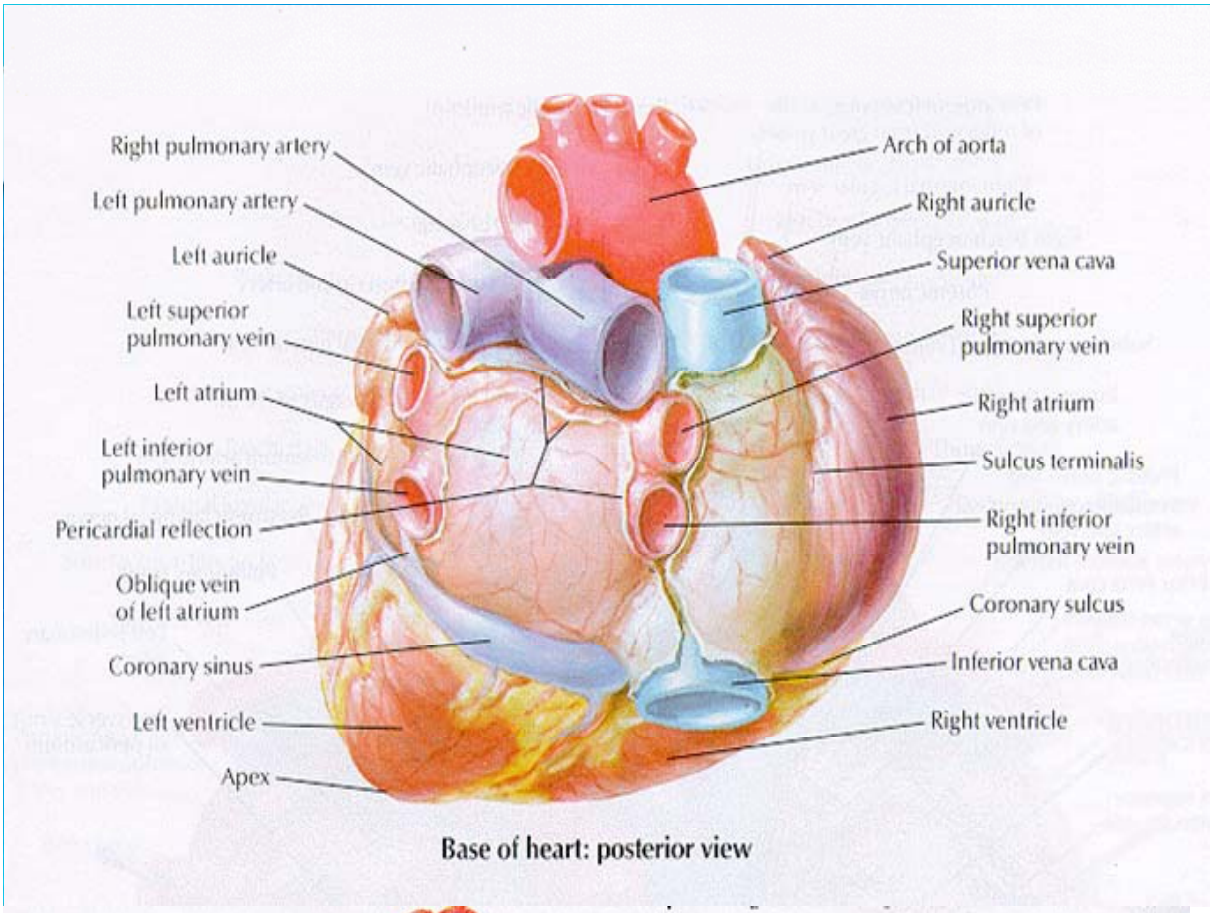
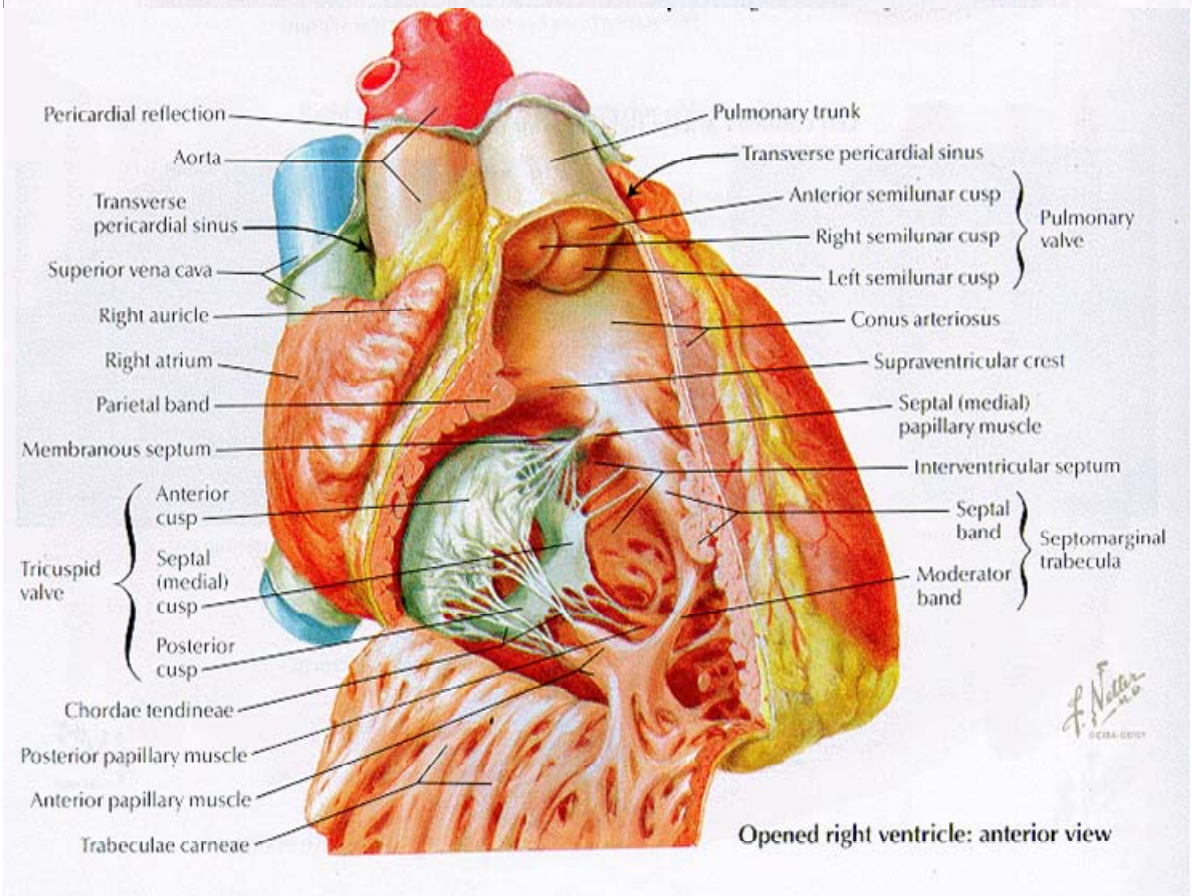



**Figure 2.5** Anatomy of the heart






Base of heart: posterior view




Opened right ventricle: anterior view

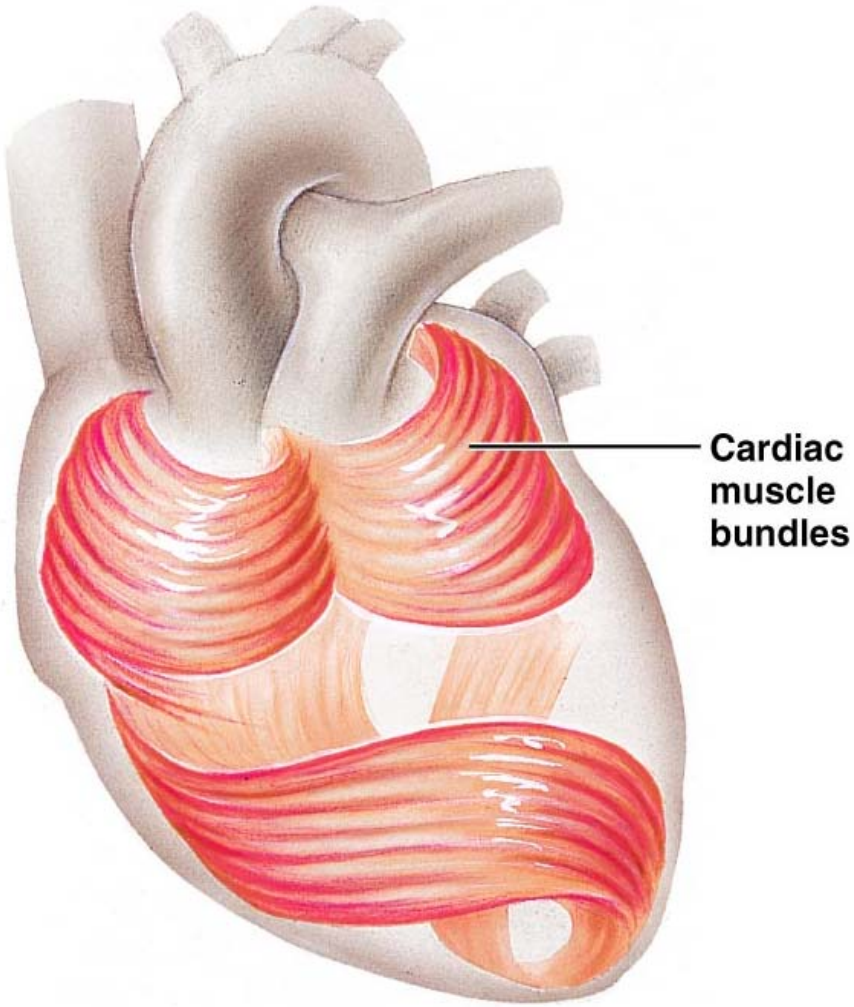
## Cardiac Muscle Bundles

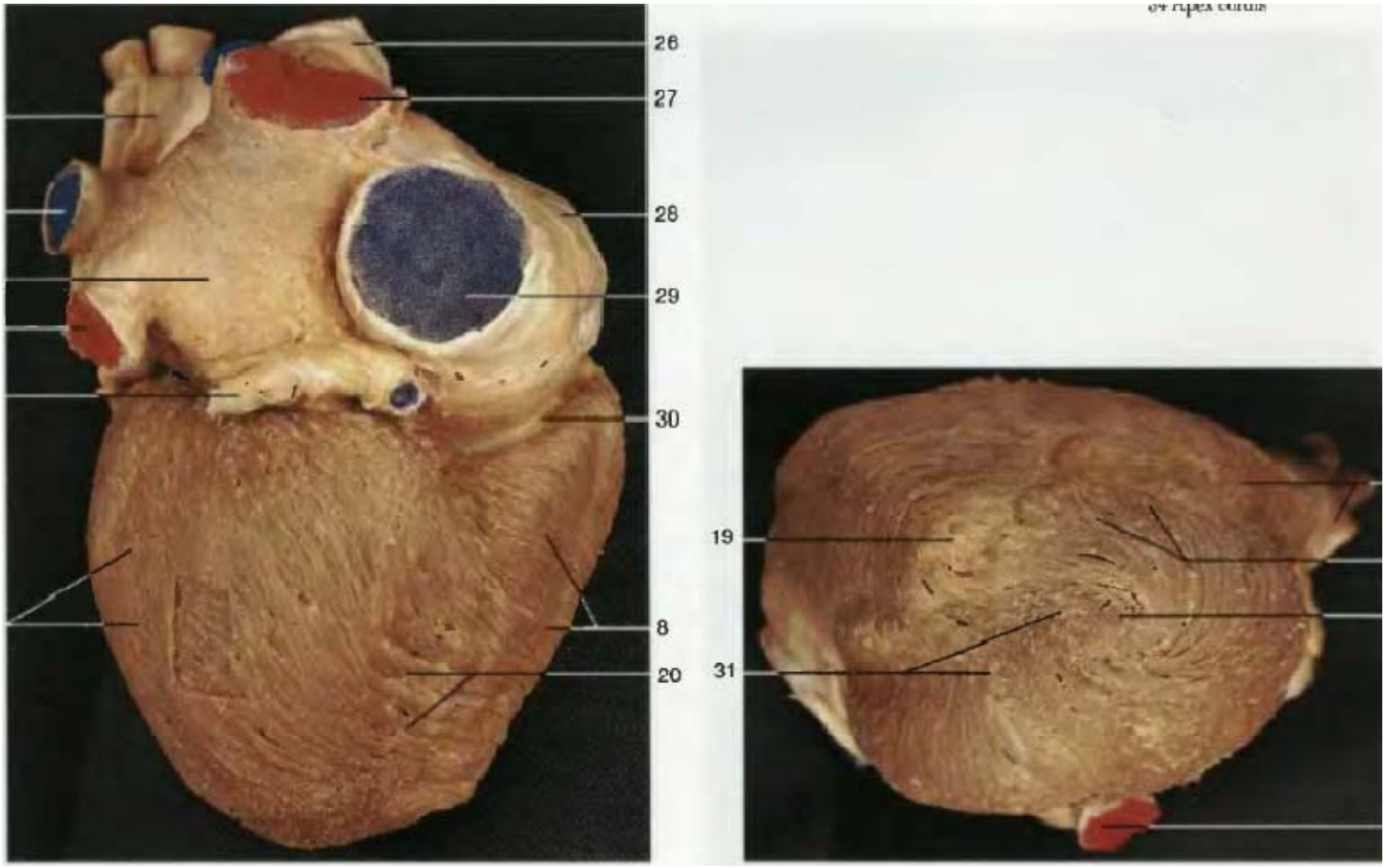
**External Heart: Major Vessels of the Heart (Anterior View)**

- Vessels returning blood to the heart include:

    - Superior and inferior venae cavae
    - Right and left pulmonary veins
- Vessels conveying blood away from the heart:
    - Pulmonary trunk, which splits into right and left pulmonary arteries
    - Ascending aorta (three branches) – brachiocephalic, left common carotid, and subclavian arteries

- Arteries – right and left coronary (in atrioventricular groove), marginal, circumflex, and anterior interventricular arteries
- Veins – small cardiac, anterior cardiac, and great cardiac veins


Cardiac
muscle
bundles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## Table 12–1 ANATOMY OF THE HEART

| Structure | Description |
|---|---|
| Epicardium | Serous membrane on the surface of the myocardium |
| Myocardium | Heart muscle; forms the walls of the four chambers |
| Endocardium | Endothelium that lines the chambers and covers the valves; smooth to prevent abnormal clotting |
| Right atrium (RA) | Receives deoxygenated blood from the body by way of the superior and inferior caval veins |
| Tricuspid valve | Right AV valve; prevents backflow of blood from the RV to the RA when the RV contracts |
| Right ventricle (RV) | Pumps blood to the lungs by way of the pulmonary artery |
| Pulmonary semilunar valve | Prevents backflow of blood from the pulmonary artery to the RV when the RV relaxes |
| Left atrium (LA) | Receives oxygenated blood from the lungs by way of the four pulmonary veins |
| Mitral valve | Left AV valve; prevents backflow of blood from the LV to the LA when the LV contracts |
| Left ventricle (LV) | Pumps blood to the body by way of the aorta |
| Aortic semilunar valve | Prevents backflow of blood from the aorta to the LV when the LV relaxes |
| Papillary muscles and chordae tendineae | In both the RV and LV; prevent inversion of the AV valves when the ventricles contract |
| Fibrous skeleton of the heart | Fibrous connective tissue that anchors the four heart valves, prevents enlargement of the valve openings, and electrically insulates the ventricles from the atria |

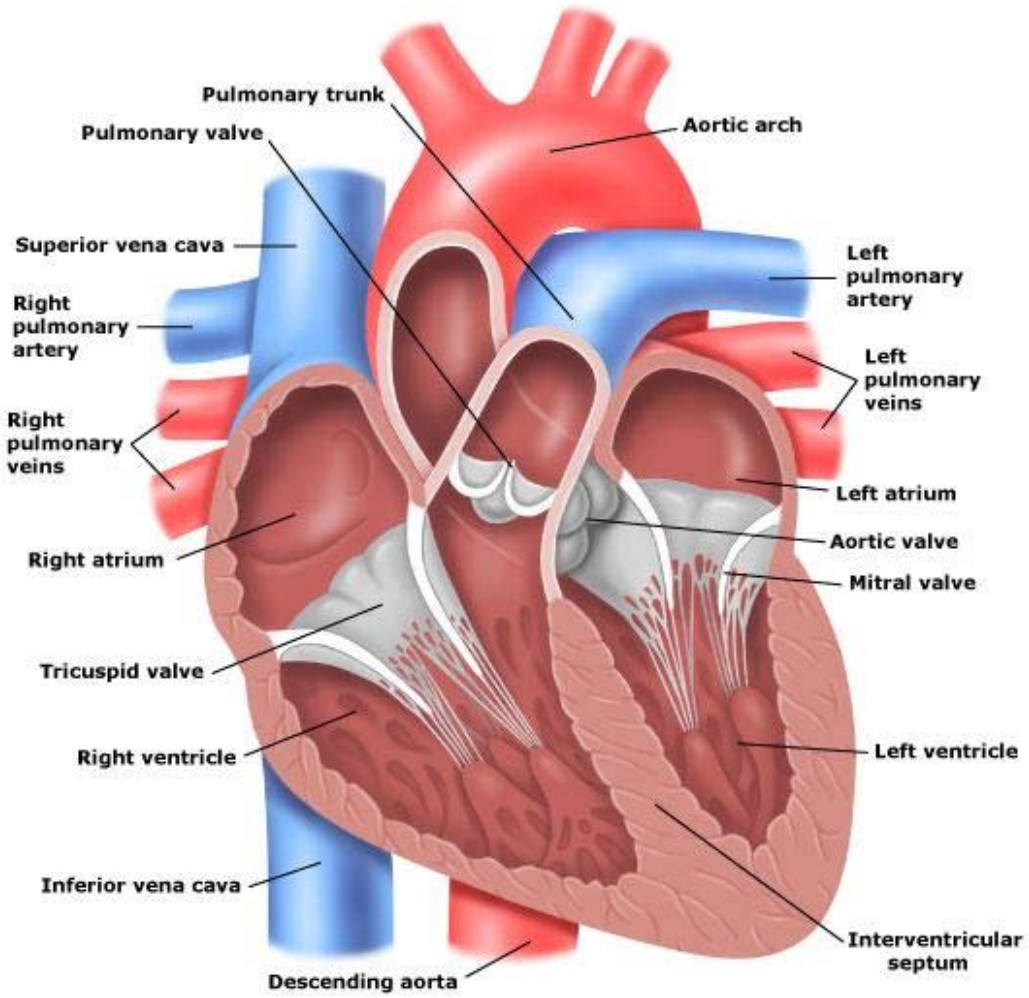


**Table 1.6 Arterial Supply of Heart**

| Artery/Branch | Origin | Course | Distribution | Anastomoses |
|---|---|---|---|---|
| ***Right coronary*** | Right aortic sinus | Follows coronary (AV) groove between atria and ventricles | Right atrium, SA and AV nodes, and posterior part of IV septum | Circumflex and anterior IV branches (left coronary artery) |
| SA nodal | Right coronary artery near its origin (in 60%) | Ascends to SA node | Pulmonary trunk and SA node | |
| Right marginal | Right coronary artery | Passes to inferior margin of heart and apex | Right ventricle and apex of heart | IV branches |
| Posterior IV | Right coronary artery (in 67%) | Runs in posterior IV groove to apex of heart | Right and left ventricles and posterior third of septum | Anterior IV branches of left coronary artery (at apex) |
| AV nodal | Right coronary artery near origin of posterior IV artery | Passes to AV node | AV node | |
| ***Left coronary*** | Left aortic sinus | Runs in AV groove and gives off anterior IV and circumflex branches | Most of left atrium and ventricle, IV septum, and AV bundles; may supply AV node | Right coronary artery |
| Anterior IV (LAD) | Left coronary artery | Passes along anterior IV groove to apex of heart | Right and left ventricles; anterior two thirds IV septum | Posterior IV branch of left coronary artery |
| Circumflex | Left coronary artery | Passes to left in AV groove and runs to posterior surface of heart | Left atrium and left ventricle | Right coronary artery |
| Left marginal | Circumflex branch | Follows left border of heart | Left ventricle | IV branches |
| Posterior IV | Left coronary artery (in 33%) | Runs in posterior IV groove to apex of heart | Right and left posterior third of IV septum | Anterior IV branch of left coronary artery |

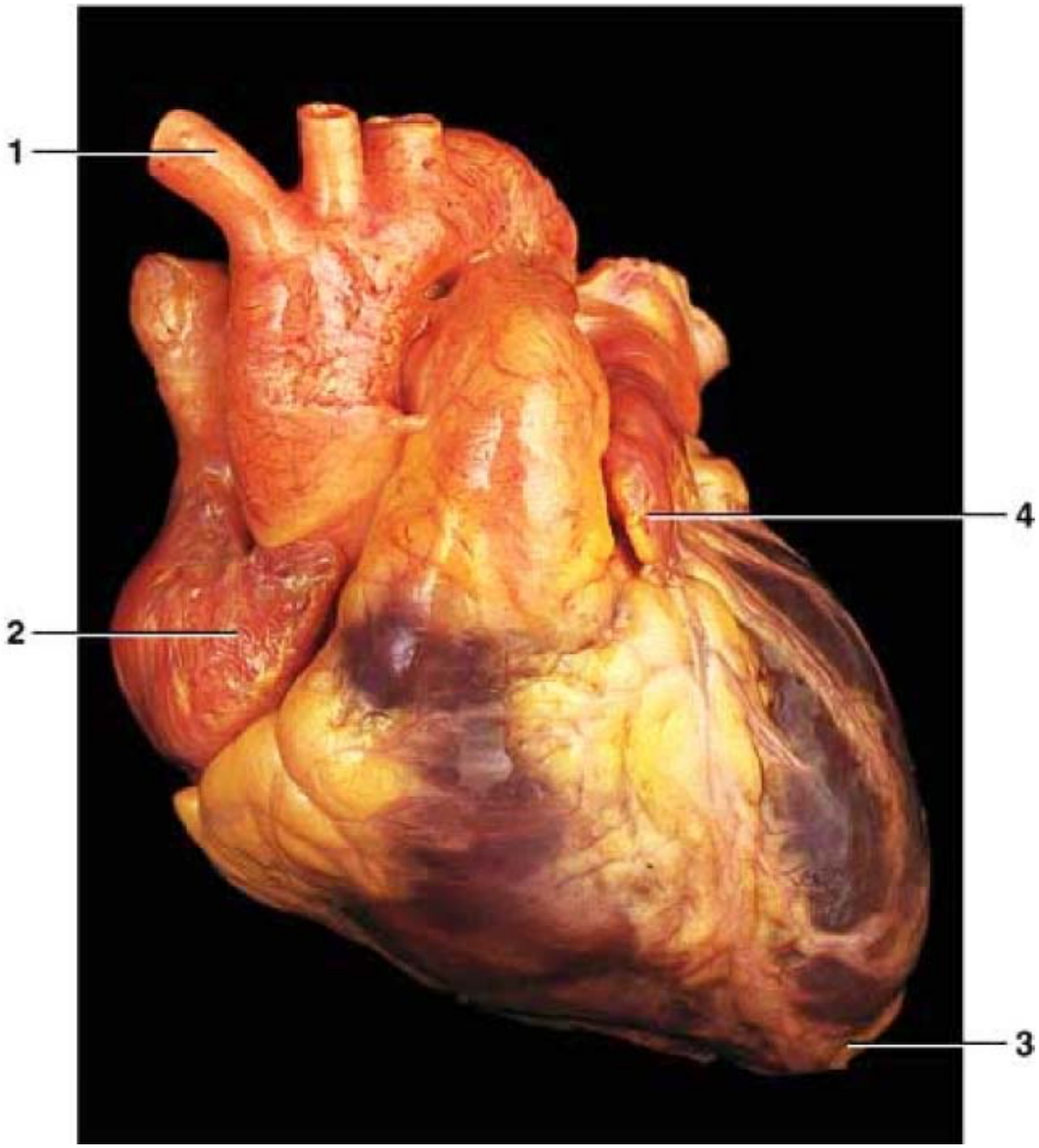
***AV***, atrioventricular; ***IV***, interventricular; ***LAD***, left anterior descending artery; ***SA***, sinuatrial.

n many people, the anterior IV artery gives rise to a **lateral (diagonal) branch**, which descends on the anterior

**External Heart: Major Vessels of the Heart (Posterior View)**

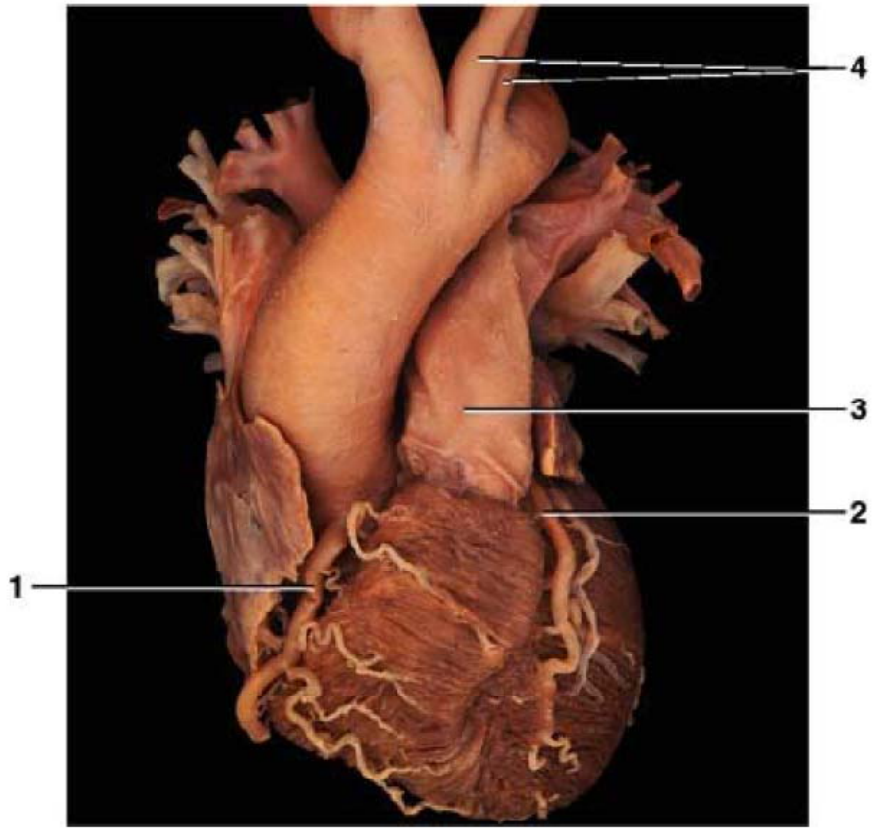
- Vessels returning blood to the heart include:
  - Right and left pulmonary veins
  - Superior and inferior venae cavae

- Vessels conveying blood away from the heart include:
  - Aorta
  - Right and left pulmonary arteries
- Arteries – right coronary artery (in atrioventricular groove) and the posterior interventricular artery (in interventricular groove)
- Veins – great cardiac vein, posterior vein to left ventricle, coronary sinus, and middle cardiac vein




## *1.14*

1. brachiocephalic trunk
2. right atrium
3. apex of heart; tip of left ventricle in fifth intercostal space
4. left auricle; represents embryological atrium




*1.15*

1. right coronary artery traversing coronary groove
2. left anterior descending artery (anterior interventricular; branch of left coronary); in anterior interventricular groove
3. pulmonary trunk
4. left common carotid and subclavian arteries; second and third branches of aorta

## CHAMBERS—VESSELS AND VALVES

The walls of the four chambers of the heart are made of cardiac muscle called the **myocardium**.
The chambers are lined with **endocardium**, simple squamous epithelium that also covers the valves of the heart and continues into the vessels as their lining (endothelium).

The important physical characteristic of the endocardium is not its thinness, but rather its smoothness.
This very smooth tissue prevents abnormal blood clotting, because clotting would be initiated by contact of blood with a rough surface.
The upper chambers of the heart are the right and left **atria** (singular: **atrium**), which have relatively thin walls and are separated by a common wall of myocardium called the **interatrial septum**.

The lower chambers are the right and left **ventricles**, which have thicker walls and are separated by the **interventricular septum** .
As you will see, the atria receive blood, either from the body or the lungs, and the ventricles pump blood to either the lungs or the body.

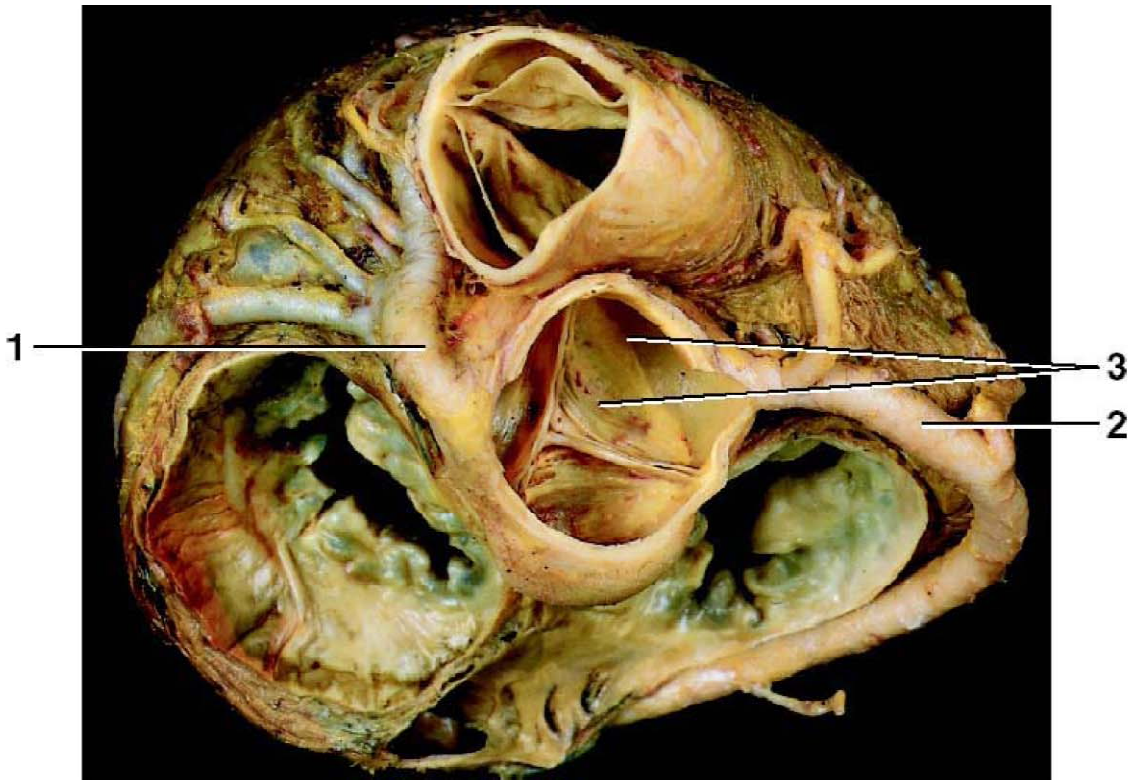
**Atria of the Heart**
- Atria are the receiving chambers of the heart
- Each atrium has a protruding auricle
- Pectinate muscles mark atrial walls
- Blood enters right atria from superior and inferior venae cavae and coronary sinus

- Blood enters left atria from pulmonary veins

**Ventricles of the Heart**
- Ventricles are the discharging chambers of the heart
- Papillary muscles and trabeculae carneae muscles mark ventricular walls
- Right ventricle pumps blood into the pulmonary trunk
- Left ventricle pumps blood into the aorta

**Pathway of Blood Through the Heart and Lungs**
- Right atrium → tricuspid valve → right ventricle
- Right ventricle → pulmonary semilunar valve → pulmonary arteries → lungs
- Lungs → pulmonary veins → left atrium
- Left atrium → bicuspid valve → left ventricle
- Left ventricle → aortic semilunar valve → aorta
- Aorta → systemic circulation

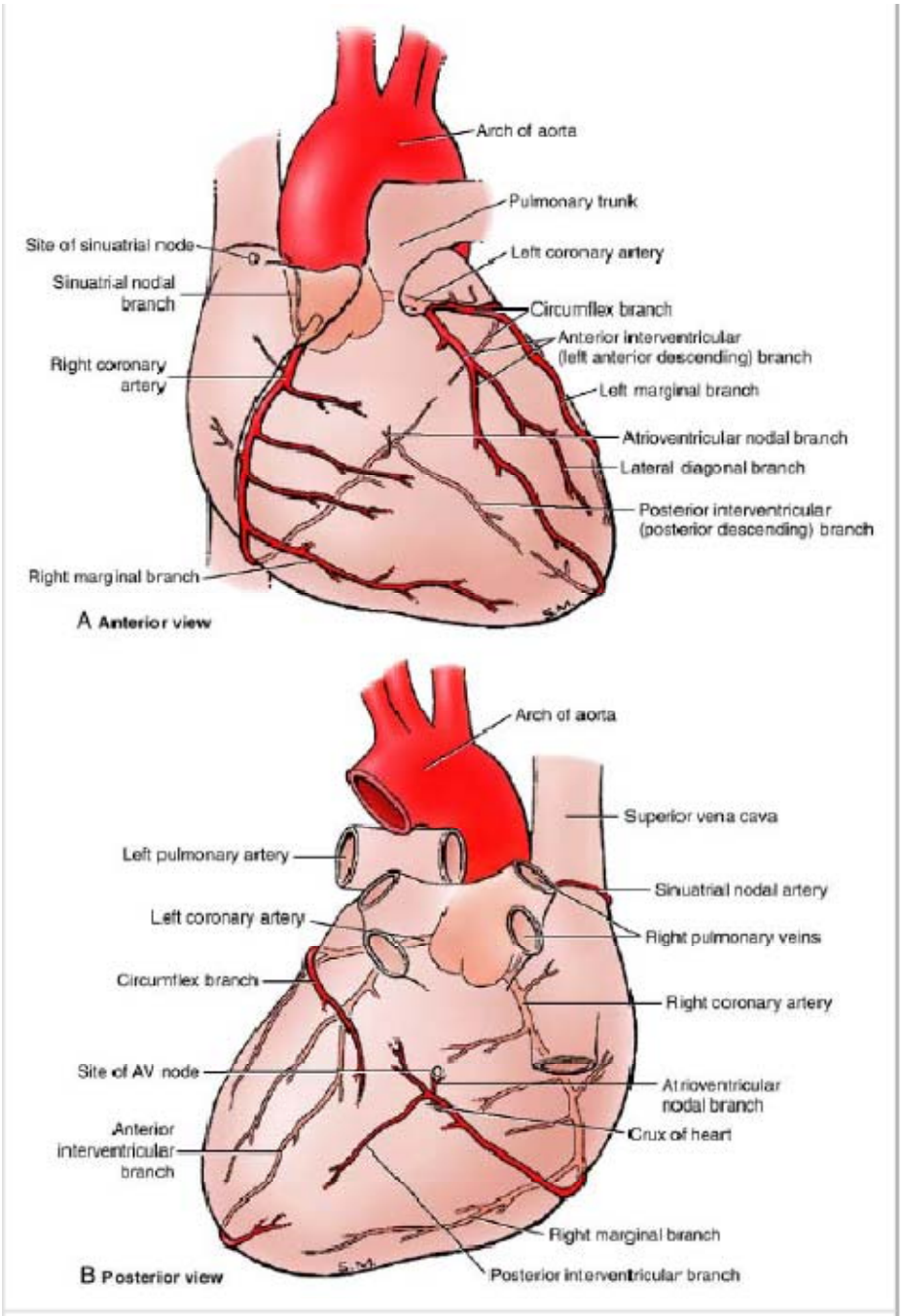
**Coronary Circulation**
- Coronary circulation is the functional blood supply to the heart muscle itself
- Collateral routes ensure blood delivery to heart even if major vessels are occluded

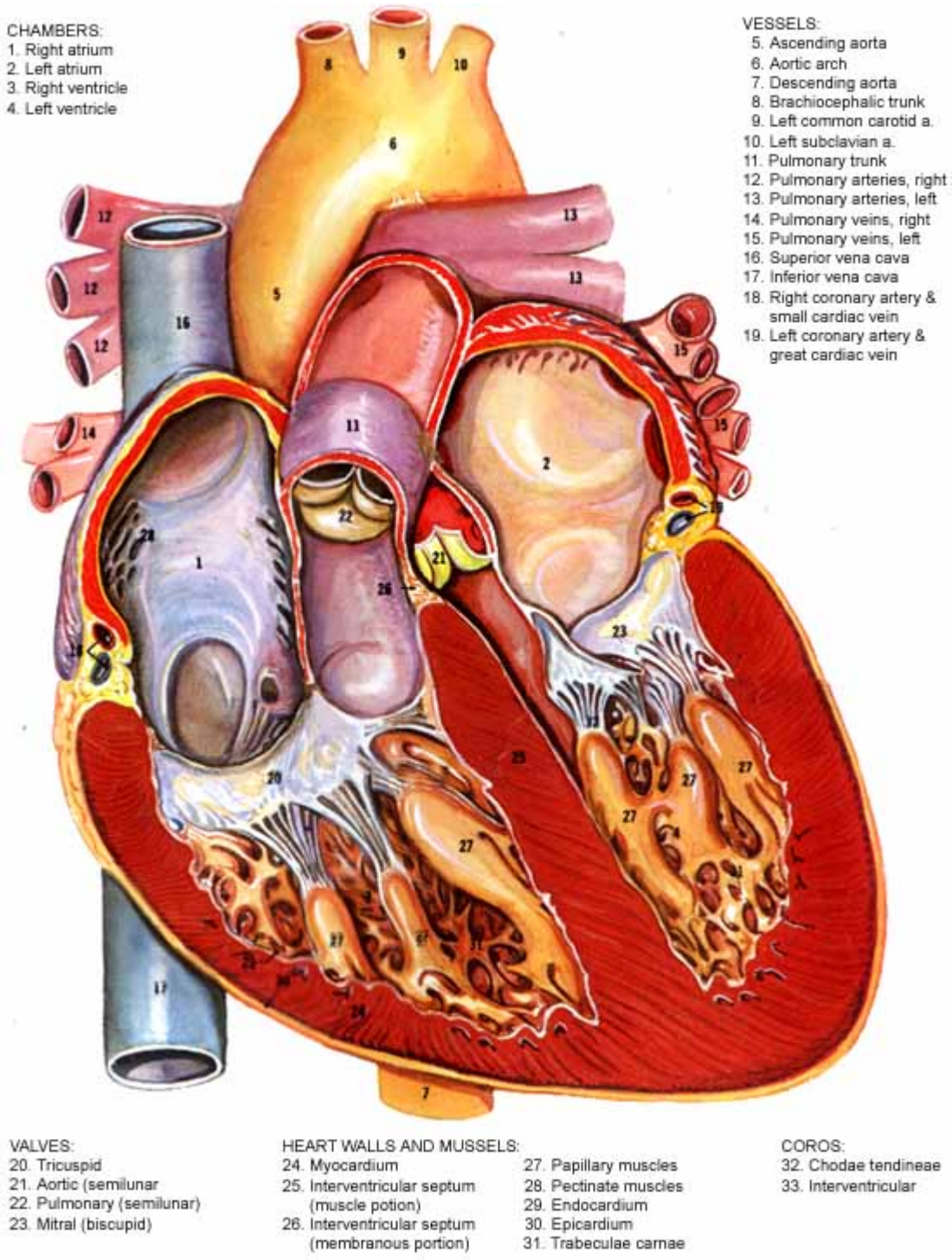





*1.16*

1. left coronary artery
2. right coronary artery
3. cusps of aortic valve; closed during diastole


Arch of aorta
Pulmonary trunk
Site of sinuatrial node
Left coronary artery
Sinuatrial nodal branch
Circumflex branch
Anterior interventricular (left anterior descending) branch
Right coronary artery
Left marginal branch
Atrioventricular nodal branch
Lateral diagonal branch
Posterior interventricular (posterior descending) branch
Right marginal branch
A Anterior view
Arch of aorta
Superior vena cava
Left pulmonary artery
Sinuatrial nodal artery
Left coronary artery
Right pulmonary veins
Circumflex branch
Right coronary artery
Site of AV node
Atrioventricular nodal branch
Anterior interventricular branch
Crux of heart
Right marginal branch
Posterior interventricular branch
B Posterior view




**Heart Valves**

- Heart valves ensure unidirectional blood flow through the heart
- Atrioventricular (AV) valves lie between the atria and the ventricles
- AV valves prevent backflow into the atria when ventricles contract
- Chordae tendineae anchor AV valves to papillary muscles
- Aortic semilunar valve lies between the left ventricle and the aorta
- Pulmonary semilunar valve lies between the right ventricle and pulmonary trunk
- Semilunar valves prevent backflow of blood into the ventricles

**Atrioventricular Valve Function**

**Semilunar Valve Function**

**Microscopic Anatomy of Heart Muscle**

- Cardiac muscle is striated, short, fat, branched, and interconnected
- The connective tissue endomysium acts as both tendon and insertion
- Intercalated discs anchor cardiac cells together and allow free passage of ions
- Heart muscle behaves as a functional syncytium

**Cardiac Muscle Contraction**

- Heart muscle:
  - Is stimulated by nerves and is self-excitable (automaticity)
  - Contracts as a unit
  - Has a long (250 ms) absolute refractory period
- Cardiac muscle contraction is similar to skeletal muscle contraction

**Heart Physiology: Intrinsic Conduction System**

- Autorhythmic cells:
  - Initiate action potentials
  - Have unstable resting potentials called pacemaker potentials
  - Use calcium influx (rather than sodium) for rising phase of the action potential

**Pacemaker and Action Potentials of the Heart**

**Cardiac Membrane Potential**

**Heart Physiology: Sequence of Excitation**

- Sinoatrial (SA) node generates impulses about 75 times/minute
- Atrioventricular (AV) node delays the impulse approximately 0.1 second
- Impulse passes from atria to ventricles via the atrioventricular bundle (bundle of His)

**Heart Physiology: Sequence of Excitation**

- AV bundle splits into two pathways in the interventricular septum (bundle branches)
  - Bundle branches carry the impulse toward the apex of the heart
  - Purkinje fibers carry the impulse to the heart apex and ventricular walls

**Cardiac Intrinsic Conduction**

**Cardiac Membrane Potential**

**Extrinsic Innervation of the Heart**

- Heart is stimulated by the sympathetic cardioacceleratory center
- Heart is inhibited by the parasympathetic cardioinhibitory center

**Electrocardiography**

- Electrical activity is recorded by electrocardiogram (ECG)
- P wave corresponds to depolarization of SA node
- QRS complex corresponds to ventricular depolarization
- T wave corresponds to ventricular repolarization
- Atrial repolarization record is masked by the larger QRS complex

**ECG Tracings**

**Heart Sounds**

**Electrocardiography**

**Heart Sounds**

- Heart sounds (lub-dup) are associated with closing of heart valves
  - First sound occurs as AV valves close and signifies beginning of systole
  - Second sound occurs when SL valves close at the beginning of ventricular diastole

**Cardiac Cycle**

- Cardiac cycle refers to all events associated with blood flow through the heart
  - Systole – contraction of heart muscle
  - Diastole – relaxation of heart muscle

**Phases of the Cardiac Cycle**

- Ventricular filling – mid-to-late diastole
  - Heart blood pressure is low as blood enters atria and flows into ventricles
  - AV valves are open, then atrial systole occurs

**Phases of the Cardiac Cycle**

- Ventricular systole
  - Atria relax
  - Rising ventricular pressure results in closing of AV valves
  - Isovolumetric contraction phase
  - Ventricular ejection phase opens semilunar valves

**Phases of the Cardiac Cycle**

- Isovolumetric relaxation – early diastole
  - Ventricles relax
  - Backflow of blood in aorta and pulmonary trunk closes semilunar valves
- Dicrotic notch – brief rise in aortic pressure caused by backflow of blood rebounding off semilunar valves

**Cardiac Output (CO) and Reserve**

- CO is the amount of blood pumped by each ventricle in one minute
- CO is the product of heart rate (HR) and stroke volume (SV)
- HR is the number of heart beats per minute
- SV is the amount of blood pumped out by a ventricle with each beat
- Cardiac reserve is the difference between resting and maximal CO

**Cardiac Output: Example**
- CO (ml/min) = HR (75 beats/min) x SV (70 ml/beat)
- CO = 5250 ml/min (5.25 L/min)

**Regulation of Stroke Volume**
- SV = end diastolic volume (EDV) minus end systolic volume (ESV)
- EDV = amount of blood collected in a ventricle during diastole
- ESV = amount of blood remaining in a ventricle after contraction

**Factors Affecting Stroke Volume**
- Preload – amount ventricles are stretched by contained blood
- Contractility – cardiac cell contractile force due to factors other than EDV
- Afterload – back pressure exerted by blood in the large arteries leaving the heart

**Frank-Starling Law of the Heart**
- Preload, or degree of stretch, of cardiac muscle cells before they contract is the critical factor controlling stroke volume
- Slow heartbeat and exercise increase venous return to the heart, increasing SV
- Blood loss and extremely rapid heartbeat decrease SV

**Preload and Afterload**

**Extrinsic Factors Influencing Stroke Volume**
- Contractility is the increase in contractile strength, independent of stretch and EDV
- Increase in contractility comes from:
  - Increased sympathetic stimuli
  - Certain hormones
  - $Ca^{2+}$ and some drugs

**Extrinsic Factors Influencing Stroke Volume**
- Agents/factors that decrease contractility include:
  - Acidosis
  - Increased extracellular $K^{+}$
  - Calcium channel blockers

**Heart Contractility and Norepinephrine**
**Regulation of Heart Rate**
- Positive chronotropic factors increase heart rate
- Negative chronotropic factors decrease heart rate

**Regulation of Heart Rate: Autonomic Nervous System**
- Sympathetic nervous system (SNS) stimulation is activated by stress, anxiety, excitement, or exercise
- Parasympathetic nervous system (PNS) stimulation is mediated by acetylcholine and opposes the SNS
- PNS dominates the autonomic stimulation, slowing heart rate and causing vagal tone

**Atrial (Bainbridge) Reflex**
- Atrial (Bainbridge) reflex – a sympathetic reflex initiated by increased blood in the atria
  - Causes stimulation of the SA node
  - Stimulates baroreceptors in the atria, causing increased SNS stimulation

**Chemical Regulation of the Heart**
- The hormones epinephrine and thyroxine increase heart rate
- Intra- and extracellular ion concentrations must be maintained for normal heart function

**Congestive Heart Failure (CHF)**
- Congestive heart failure (CHF) is caused by:

- Coronary atherosclerosis
- Persistent high blood pressure
- Multiple myocardial infarcts
- Dilated cardiomyopathy (DCM)

**Developmental Aspects of the Heart**

- Embryonic heart chambers
  - Sinus venous
  - Atrium
  - Ventricle
  - Bulbus cordis
- Fetal heart structures that bypass pulmonary circulation
  - Foramen ovale connects the two atria
  - Ductus arteriosus connects pulmonary trunk and the aorta

**Examples of Congenital Heart Defects**

**Age-Related Changes Affecting the Heart**

- Sclerosis and thickening of valve flaps
- Decline in cardiac reserve
- Fibrosis of cardiac muscle
- Atherosclerosis

| New Terminology | Related Clinical Terminology |
|---|---|
| Aorta (ay-**OR**-tah)<br>Atrium (**AY**-tree-um)<br>Cardiac cycle (**KAR**-dee-yak **SIGH**-kuhl)<br>Cardiac output (**KAR**-dee-yak **OUT**-put)<br>Coronary arteries (**KOR**-uh-na-ree **AR**-tuh-rees)<br>Diastole (dye-**AS**-tuh-lee)<br>Endocardium (EN-doh-**KAR**-dee-um)<br>Epicardium (EP-ee-**KAR**-dee-um)<br>Mediastinum (ME-dee-ah-**STYE**-num)<br>Mitral valve (**MY**-truhl VALV)<br>Myocardium (MY-oh-**KAR**-dee-um)<br>Sinoatrial (SA) node (**SIGH**-noh-AY-tree-al NOHD)<br>Stroke volume (STROHK **VAHL**-yoom)<br>Systole (**SIS**-tuh-lee)<br>Tricuspid valve (try-**KUSS**-pid VALV)<br>Venous return (**VEE**-nus ree-**TURN**)<br>Ventricle (**VEN**-tri-kuhl) | Arrhythmia (uh-**RITH**-me-yah)<br>Ectopic focus (ek-**TOP**-ik **FOH**-kus)<br>Electrocardiogram (ECG) (ee-LEK-troh-**KAR**dee-oh-GRAM)<br>Fibrillation (fi-bri-**LAY**-shun)<br>Heart murmur (HART **MUR**-mur)<br>Ischemic (iss-**KEY**-mik)<br>Myocardial infarction (MY-oh-**KAR**-dee-yuhl in-**FARK**-shun)<br>Pulse (PULS)<br>Stenosis (ste-**NOH**-sis) |