The functional anatomy of the heart. Development of the heart, anomalies

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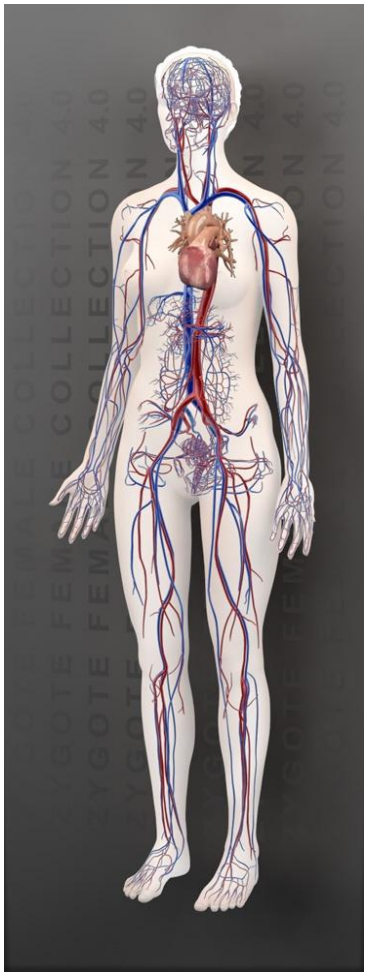
Plan:

- Cardiovascular system – general information
- Heart – functional anatomy
- Development of the heart
- Abnormalities of the heart
- Individual and age peculiarities of the heart
- Examination on a living person

Cardiovascular system

Cardiovascular system (also known as ***vascular system***, or ***circulatory system***) consists of:

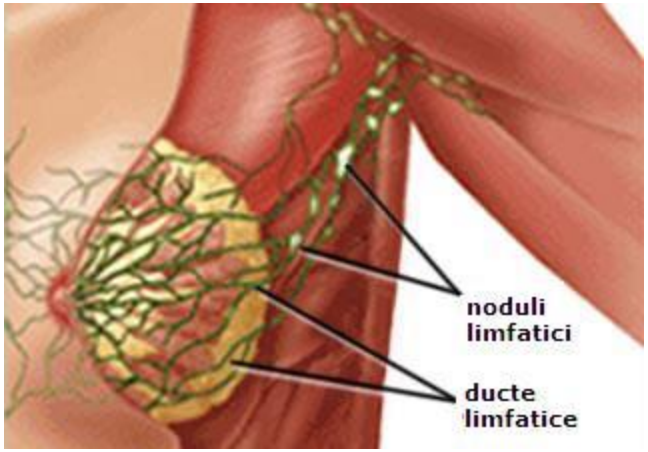
1. **heart**;
2. **blood vessels** (arteries, veins, capillaries);
3. **lymphatic vessels**.



Blood vessels

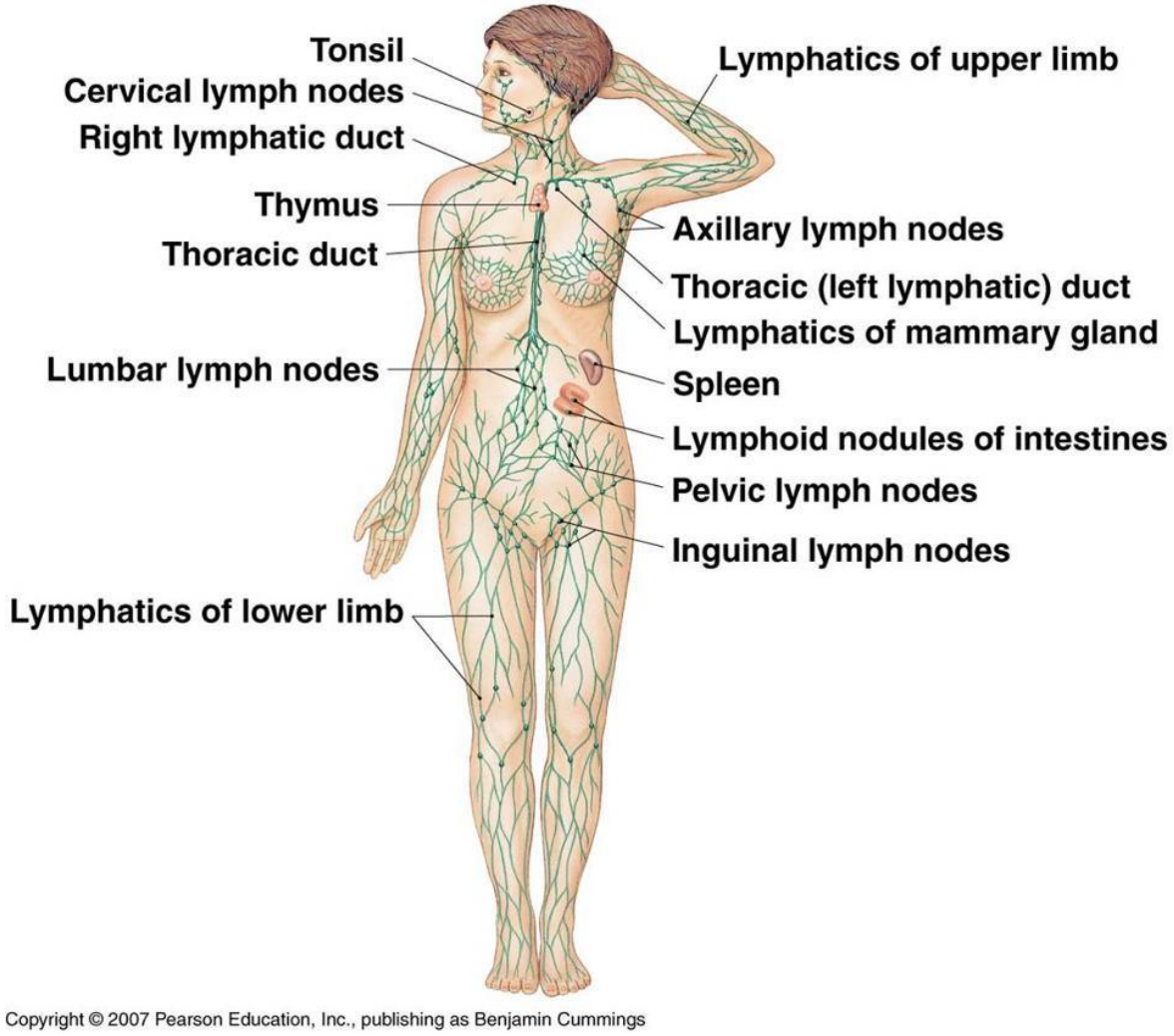
- ***Arteries*** are blood vessels that carry blood away from the heart.
- ***Veins*** carry blood back towards the heart.
- ***Capillaries*** are tiny blood vessels, that connect arteries to veins.

Lymphatic vessels:



- ***lymphatic capillaries***;
- ***lymphatic vessels*** (superficial and deep lymph vessels);
- ***lymphatic trunks*** (jugular, subclavian, bronchomediastinal, lumbar, intestinal trunks);
- ***lymphatic ducts*** (thoracic duct and right lymphatic duct).

Lymphatic vessels

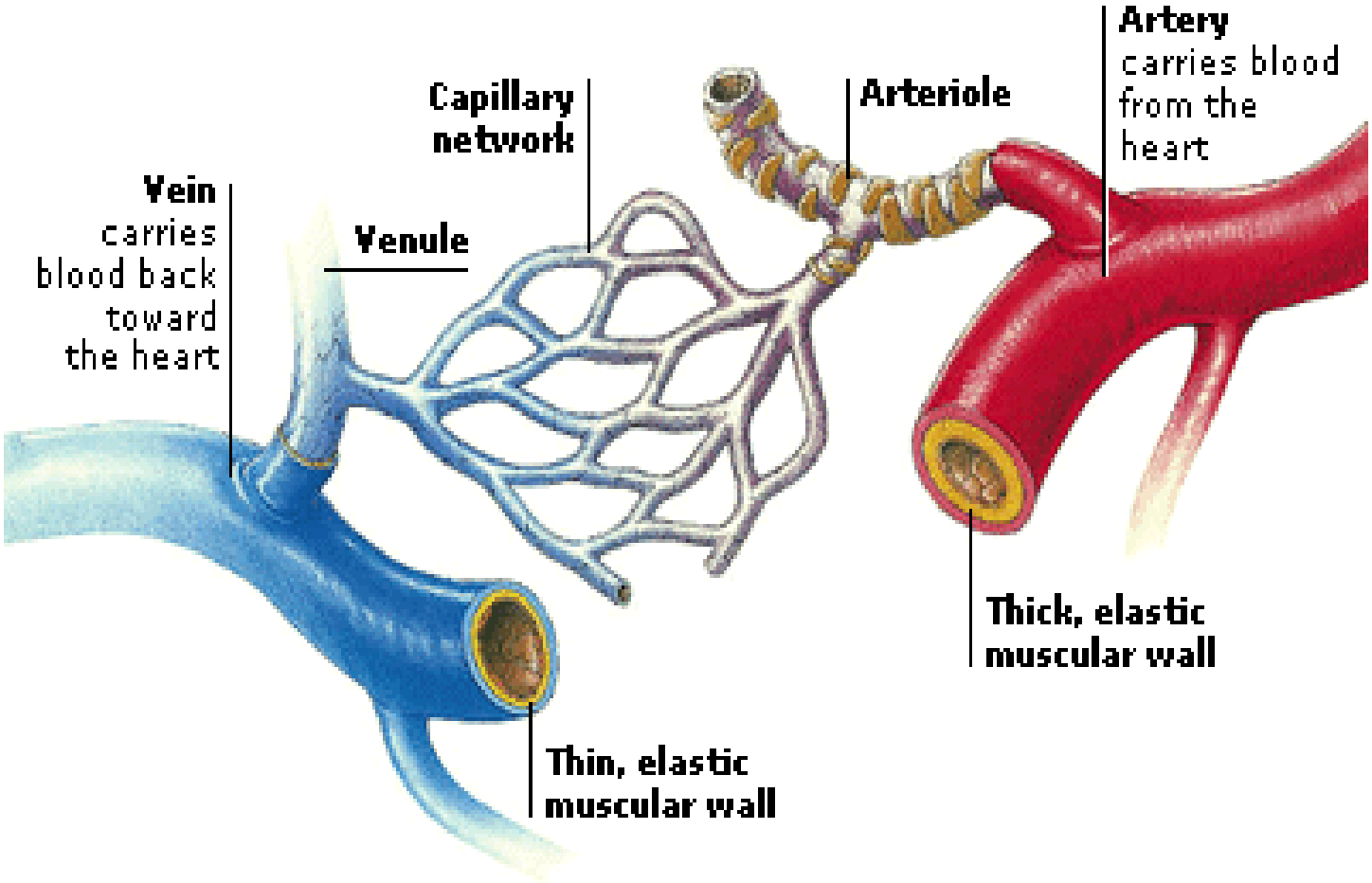


Microcirculation

Microcirculatory bed comprises 7 components:

1. ***arterioles;***
2. ***precapillaries or precapillary arterioles;***
3. ***capillaries;***
4. ***postcapillaries or postcapillary venules;***
5. ***venules;***
6. ***lymphatic capillaries;***
7. ***interstitial component.***

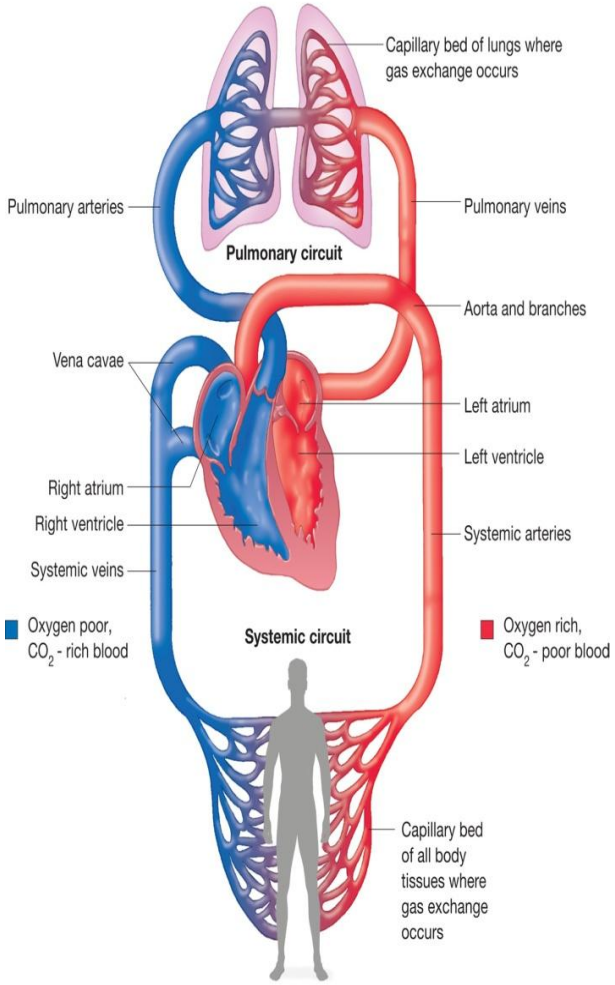
Microcirculation



Systemic blood circulation

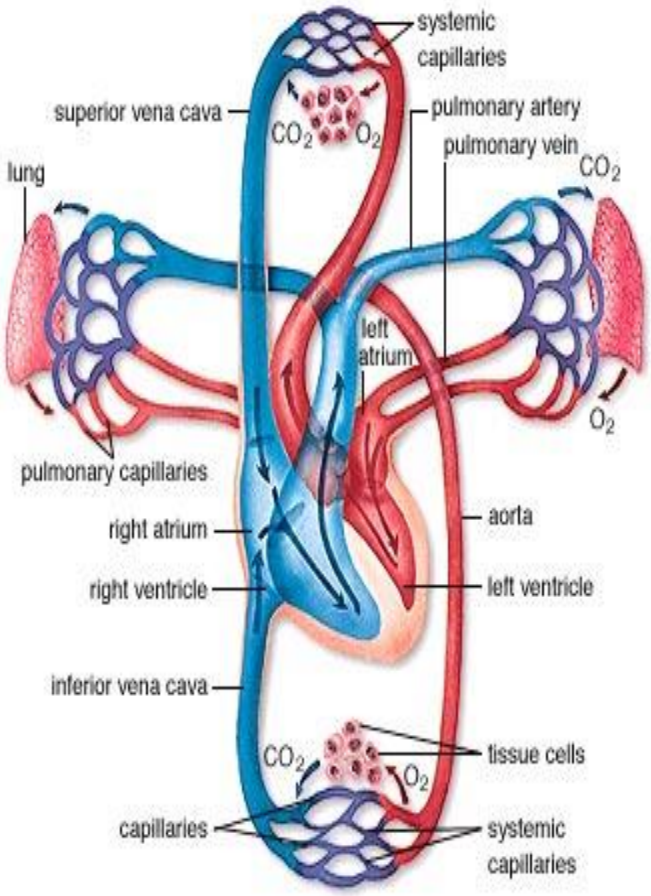
Cardiovascular system is a double circulatory system. It comprises two separate circuits (or circulations).

- **Systemic circulation**. The ***left ventricle*** pumps oxygenated blood into the main artery – ***aorta***. The blood travels from the aorta to larger and smaller arteries into the capillary network. There blood releases oxygen, nutrients and takes on carbon dioxide and wastes. The venous blood is collected in ***superior*** and ***inferior venae cavae*** and travels into the ***right atrium***.



Pulmonary blood circulation

- **Pulmonary circulation**. The ***right ventricle*** pumps venous blood into the ***pulmonary trunk***, which is divided into two ***pulmonary arteries*** (for each lung). Pulmonary artery branches off into smaller and smaller arteries and capillaries. The capillaries form a tiny network around the alveoli. There blood releases carbon dioxide and takes oxygen. Arterial blood travels through the ***pulmonary veins*** to the ***left atrium***.



The heart

Heart is shaped as a pyramid with:

- an ***apex*** (directed downward, forward and to the left);
- a ***base*** (facing upward, backward and to the right).

There are four surfaces of the heart:

- ***sternocostal*** (anterior) ***surface***;
- ***diaphragmatic*** (inferior) ***surface***;
- ***right pulmonary surface***;
- ***left pulmonary surface***.

The heart

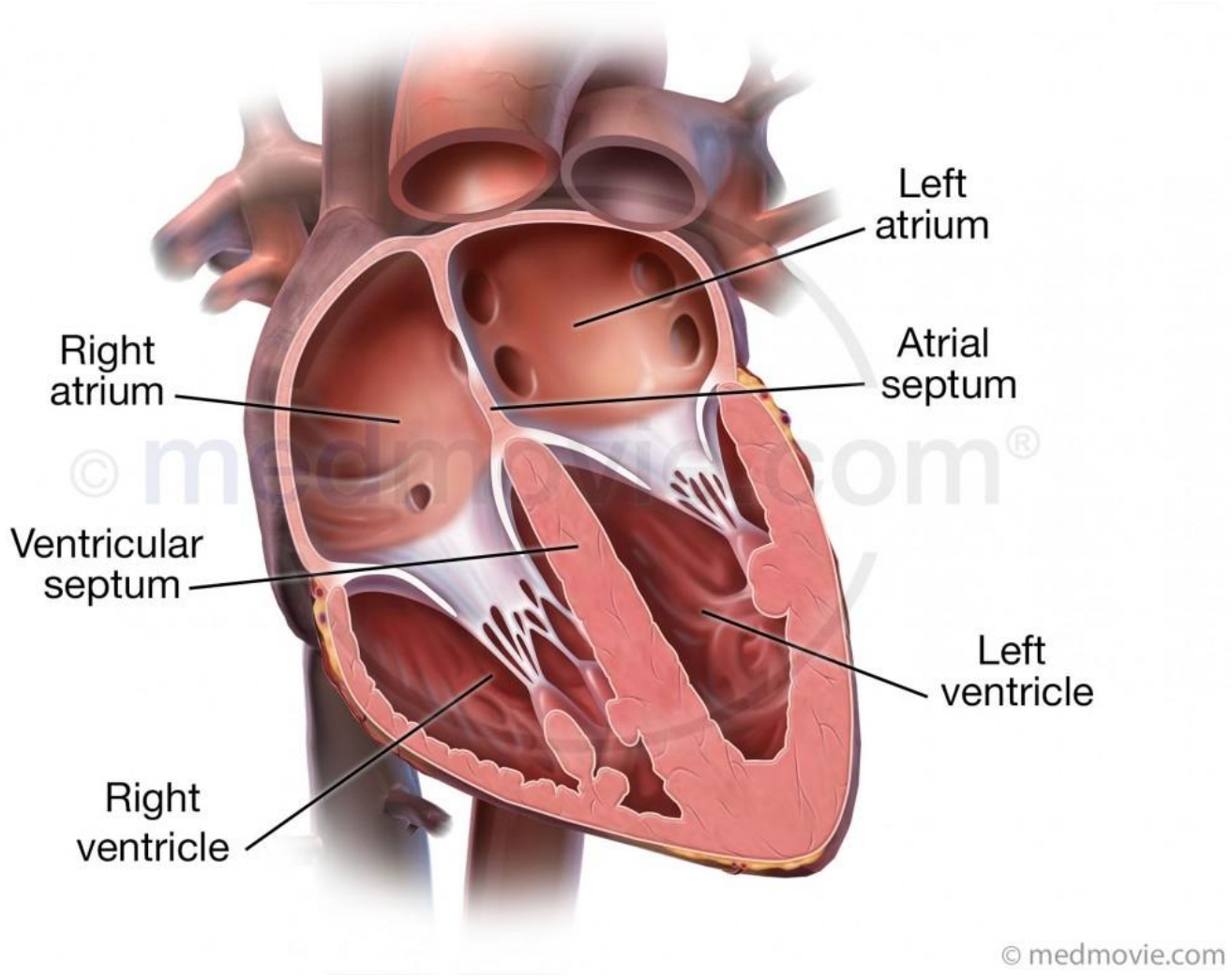
The heart has four chambers:

- ***right*** and ***left atria***;
- ***right*** and ***left ventricles***.

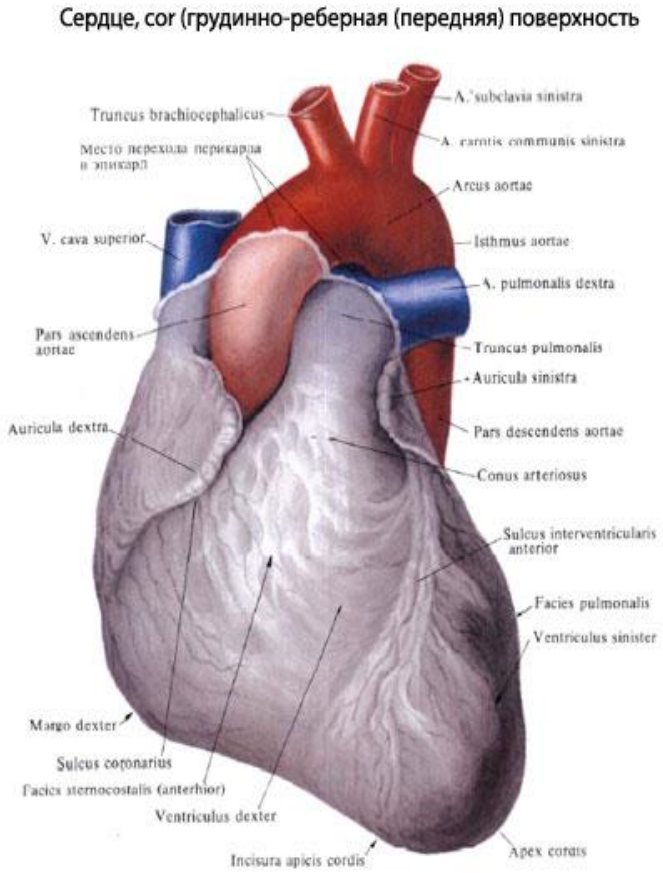
Externally, the atria are demarcated from the ventricles by ***coronary groove*** (L. *sulcus coronarius*).

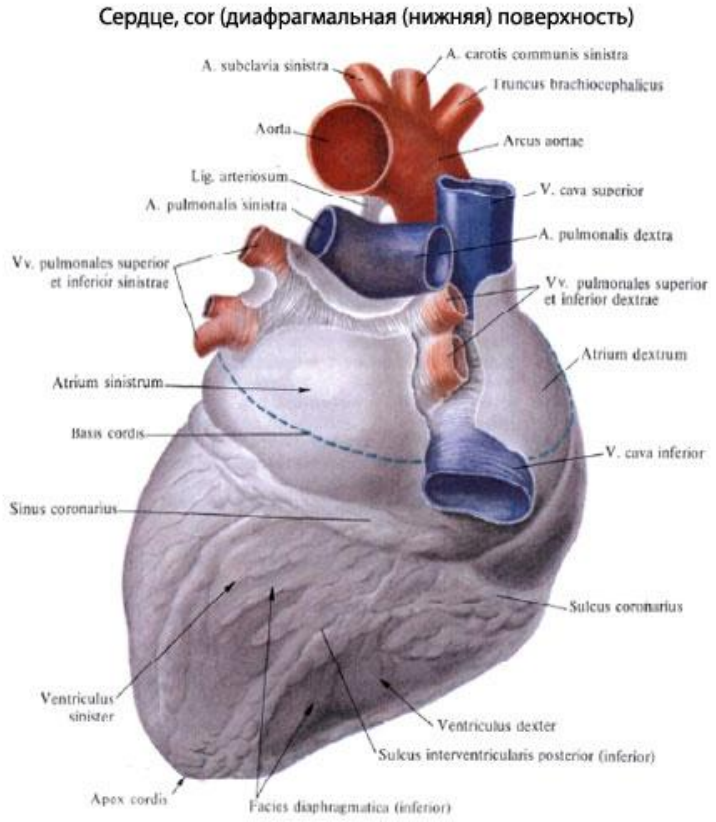
The right and left ventricles are demarcated from each other by ***anterior*** and ***posterior interventricular grooves*** (L. *sulci interventriculares anterior et posterior*).

Chambers of the heart



External surface of the heart





The atria

The atria are thin-walled chambers, that receive blood from the veins and pump it into the ventricles. They are separated by ***interatrial septum***.

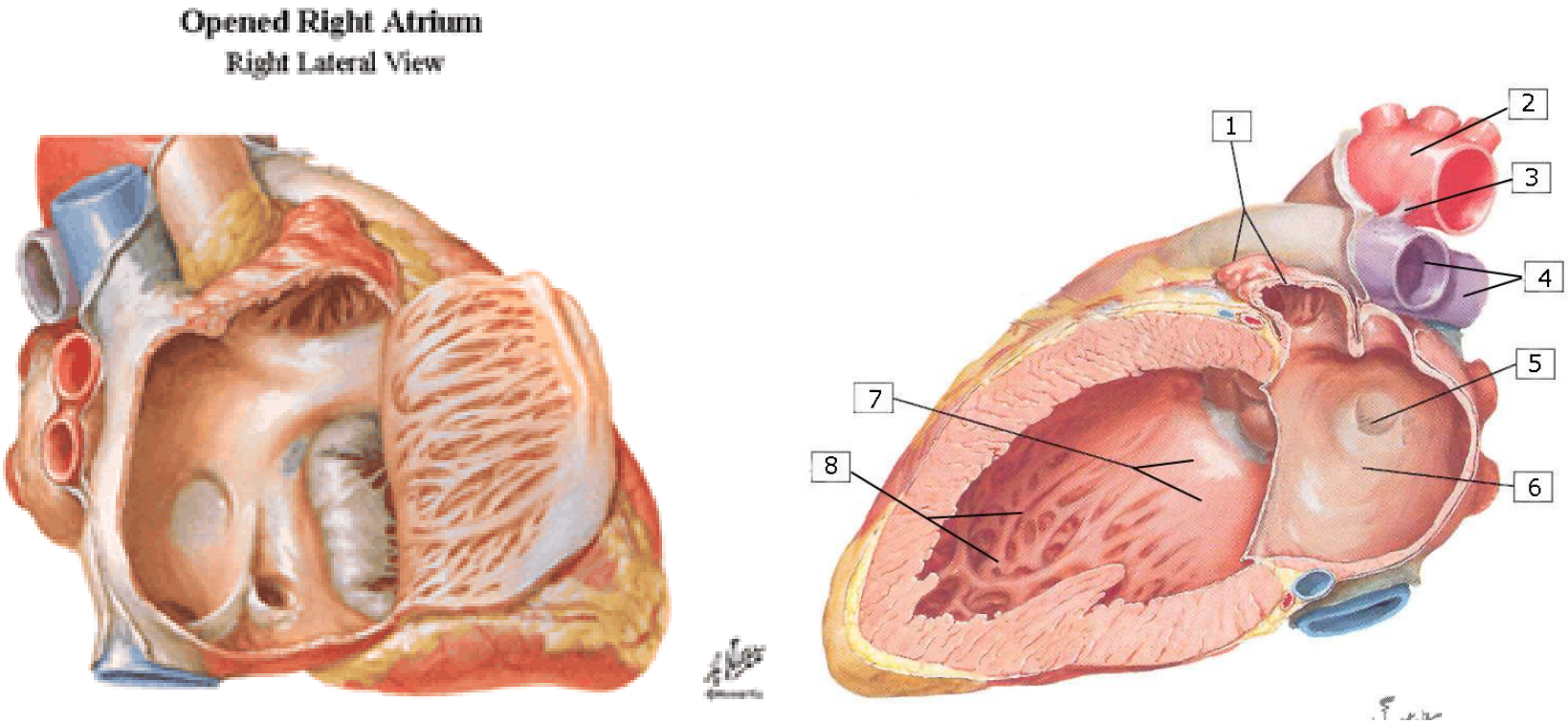
- The **right atrium** (RA) receives venous blood from the ***superior vena cava*** (SVC), ***inferior vena cava*** (IVC) and ***coronary sinus.***
- The **left atrium** (LA) receives arterial blood from the ***right*** and ***left pulmonary veins*** (four in number).

Right atrium

The interior of the **right atrium** (RA) has:

1. a smooth, thin-walled, posterior part (the ***sinus venarum***) on which the venae cavae (SVC and IVC) and coronary sinus open;
2. a rough, muscular anterior wall composed of the ***pectinate muscles;***
3. a right ***atrioventricular*** (AV) ***orifice*** through which the right atrium discharges blood into the right ventricle;
4. the interatrial septum separating the atria has an oval depression, the ***oval fossa***, which is a remnant of the *oval foramen*.

The atria



Left atrium

The interior of the **left atrium** (LA) has:

1. a larger smooth-walled part in which the pulmonary veins enter;
2. a left ***atrioventricular*** (AV) ***orifice*** through which the left atrium discharges blood into the left ventricle;
3. the interatrial septum with a *semilunar depression*, which indicates the floor of the oval fossa.

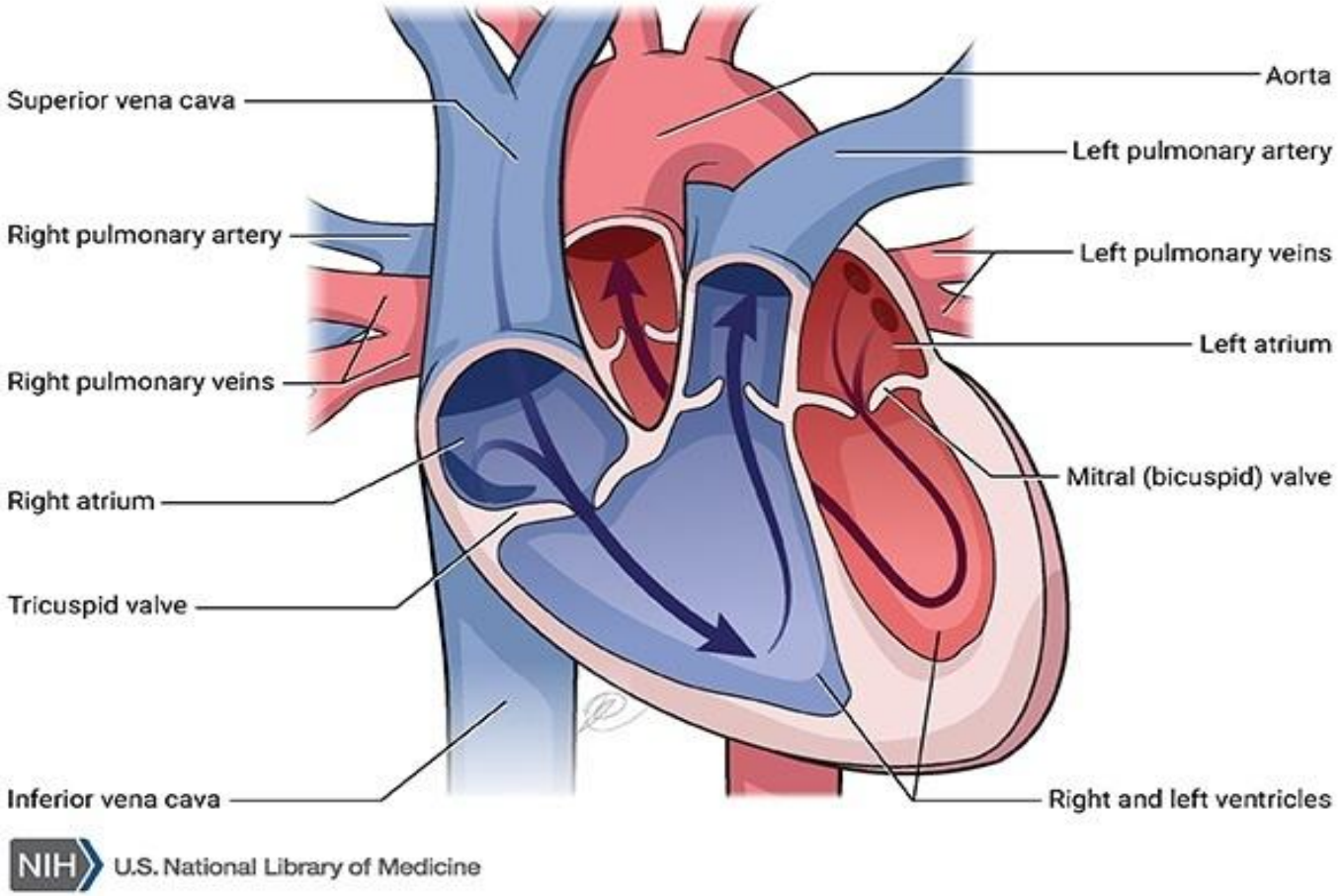
The ear-like **auricles,** muscular pouches that project like add-on rooms, increase the capacity of the atria.

The ventricles

The ventricles are thick-walled chambers, that pump blood out of the heart, into the arteries. They are separated by the ***interventricular septum***, composed of *muscular* and *membranous parts*.

- The **right ventricle** (RV) pumps blood into ***pulmonary trunk***, which is divided in two ***pulmonary arteries*** (right and left for each lung; to the *pulmonary blood circulation*).
- The **left ventricle** (LV) pumps blood into ***aorta***, which carries blood to the entire body (to the *systemic blood circulation*).

The ventricles



Right ventricle

- The internal surface of the right ventricle has irregular muscular elevations (***trabeculae carnea***) and ***papillary muscles*** (anterior, posterior, septal).

- The *inflow tract* of the ventricle receives blood from the right atrium through the ***right atrioventricular*** (AV) ***orifice***. The ***right AV valve*** or ***tricuspid valve*** guards this orifice.
- The *outflow tract* or arterial cone, the ***conus arteriosus*** (*infundibulum*) leads into the pulmonary trunk. The ***pulmonary valve*** guards the orifice of pulmonary trunk.

Left ventricle

- The internal surface of the left ventricle has irregular muscular elevations (***trabeculae carnea***) and ***papillary muscles*** (anterior and posterior).

- The *inflow tract* of the ventricle receives blood from the left atrium through the ***left atrioventricular*** (AV) ***orifice***. The ***left AV valve*** or ***bicuspid (mitral) valve*** guards this orifice.
- The *outflow tract*, the ***aortic vestibule,*** leads into the aorta. The ***aortic valve*** guards the orifice of aorta.

Valves of the heart

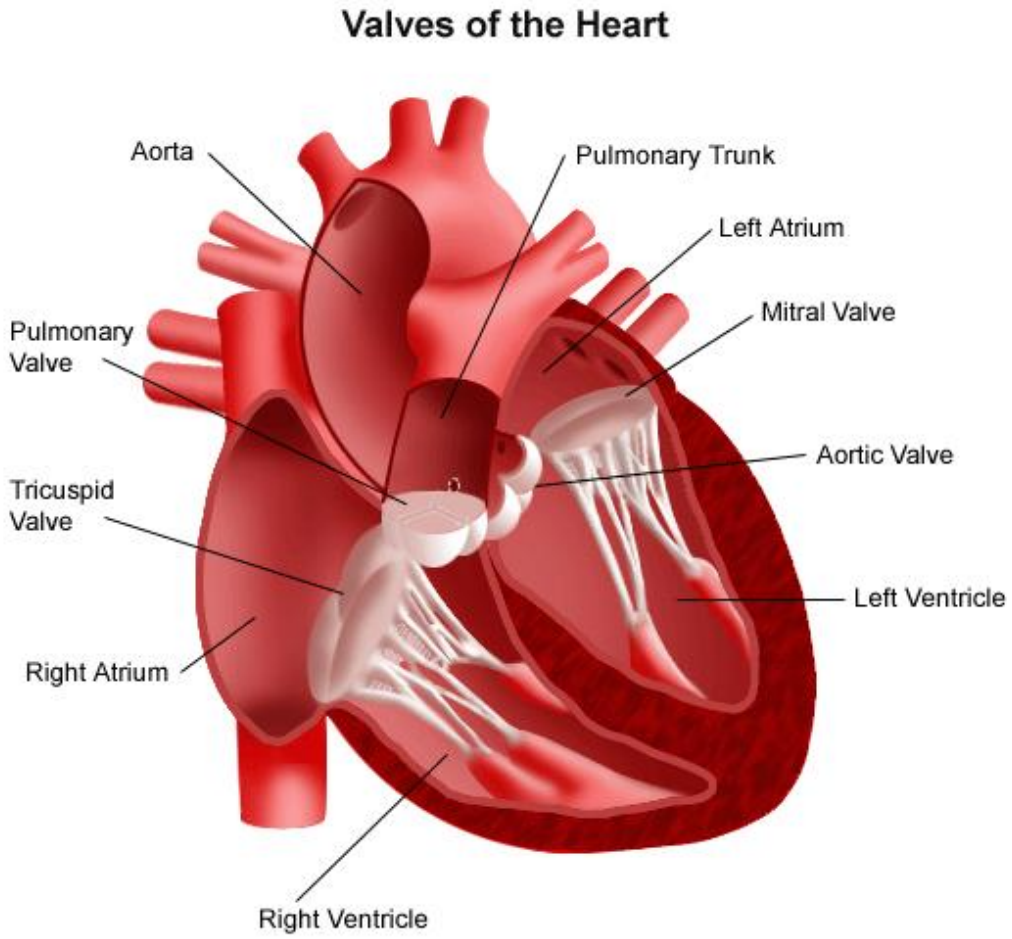
The heart valves allow blood to flow smoothly and freely in one direction.

- There are two ***atrioventricular (AV) valves*** (right and left), which allow blood to flow from the atria to the ventricles.

a) The ***right AV valve*** or ***tricuspid valve*** consists of three *cusps* (or leaflets): *anterior, posterior* and *septal.*

b) The ***left AV valve*** or ***bicuspid valve*** consists of two *cusps* (or leaflets): *anterior* and *posterior*. It resembles a *bishop`s miter* (headdress), that`s why it is named ***mitral valve*** too.

Valves of the heart



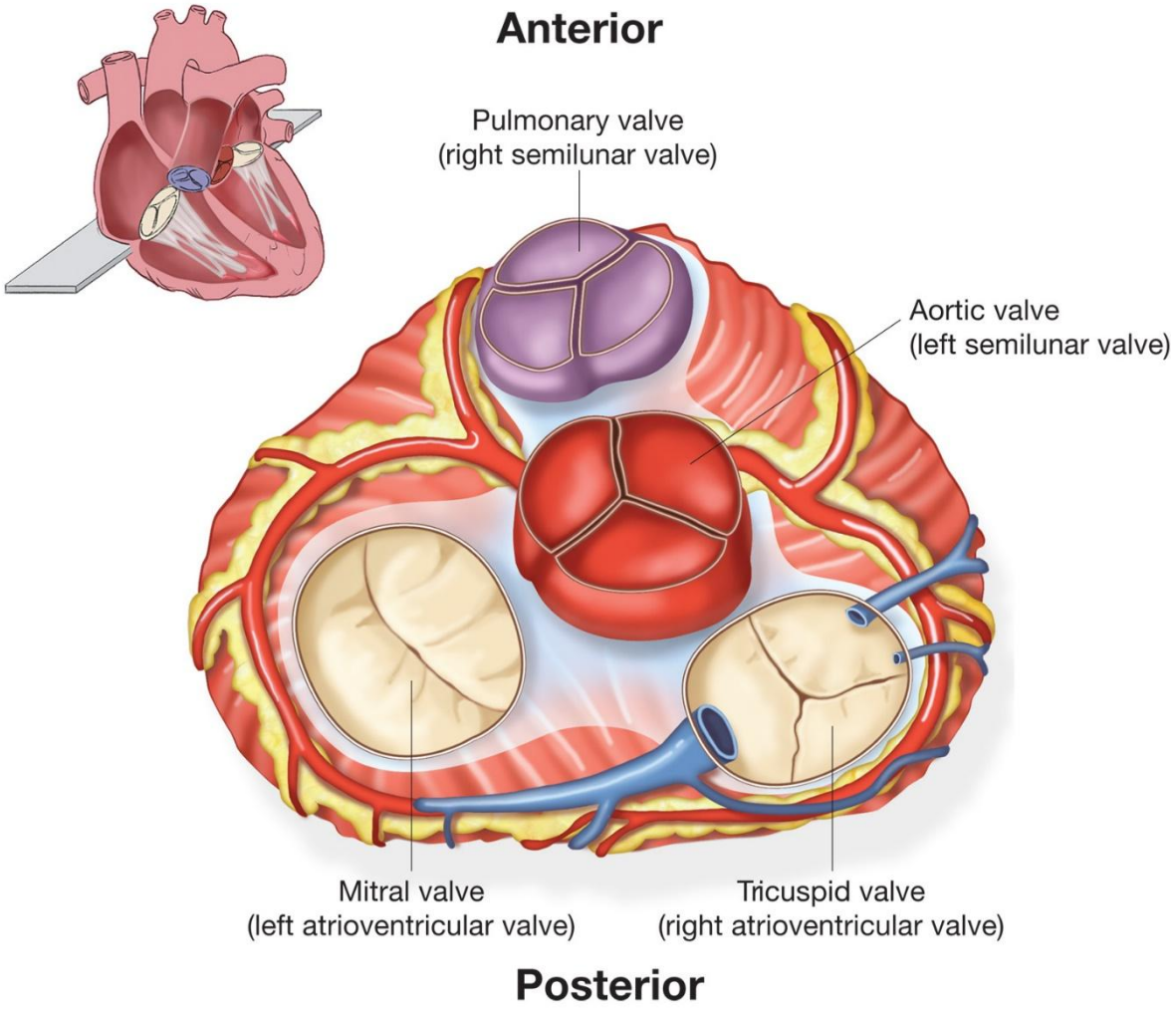
Valves of the heart

- There are two ***semilunar valves,*** which allow blood to flow out of the ventricles, into the arteries (into the aorta and the pulmonary trunk).

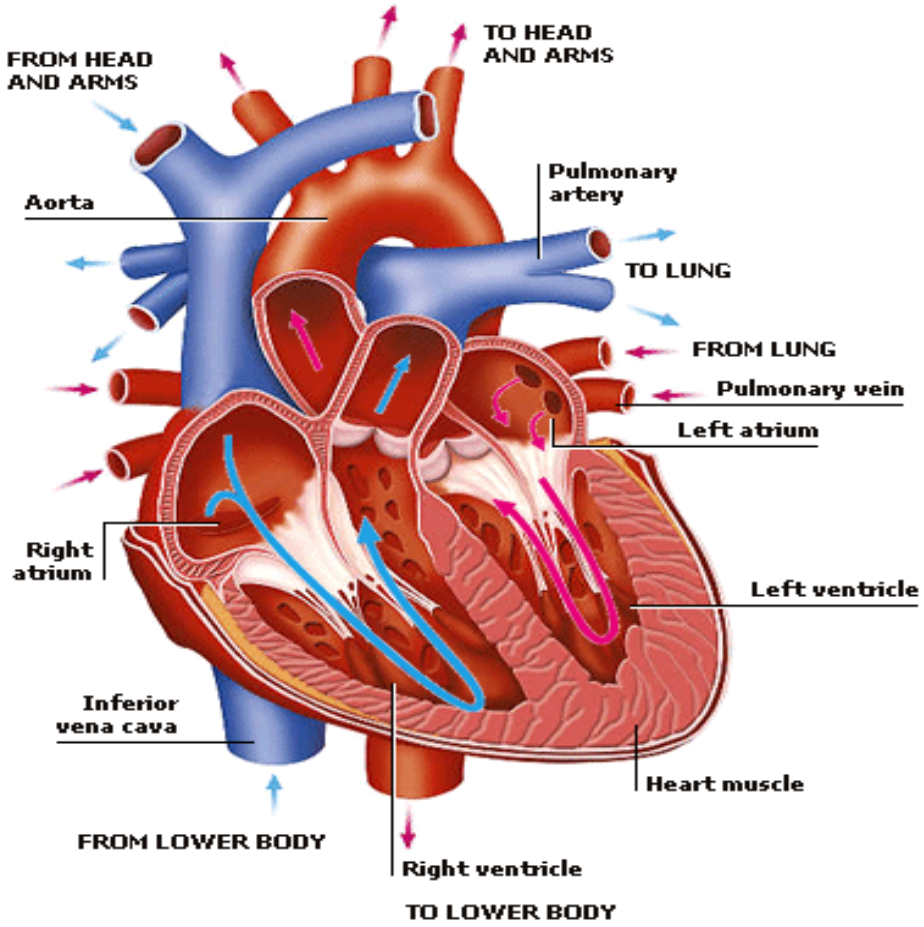
a) The ***pulmonary valve*** consists of three *semilunar cusps*: anterior, right and left.

b) The ***aortic valve*** consists of three *semilunar cusps*: posterior, right and left.

Valves of the heart



The heart

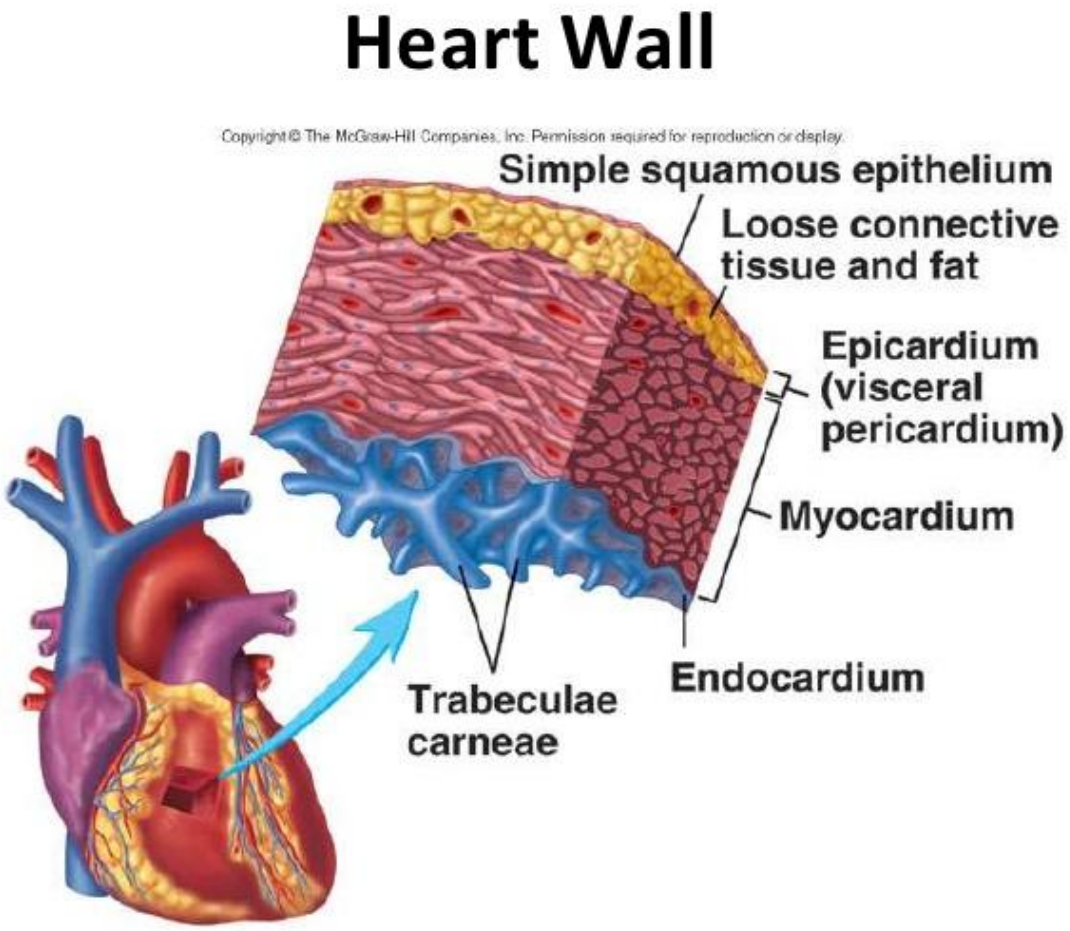

FROM HEAD AND ARMS
TO HEAD AND ARMS
Aorta
Pulmonary artery
TO LUNG
FROM LUNG
Pulmonary vein
Left atrium
Right atrium
Left ventricle
Inferior vena cava
Heart muscle
FROM LOWER BODY
Right ventricle
TO LOWER BODY

Structure of the walls of the heart

The wall of each heart chamber consists of three layers:

- **endocardium**, a thin internal layer;
- **myocardium**, a thick middle layer composed of cardiac muscle;
- **epicardium**, a thin external layer formed by the visceral layer of serous pericardium.

Structure of the walls of the heart



Structure of the walls of the heart

- **Endocardium** lines the inner surface of the heart chambers. The heart valves are folds of the endocardium.

- **Myocardium** consists of two types of cardiac muscle cells (cardiomyocytes): ***typical*** (contractile) ***cardiomyocytes*** and ***atypica***l (cells of the conducting system of the heart) ***cardiomyocytes***.
- Myocardium comprises two parts:

a. ***myocardium of the atria*** (2 layers);
b. ***myocardium of the ventricles*** (3 layers).

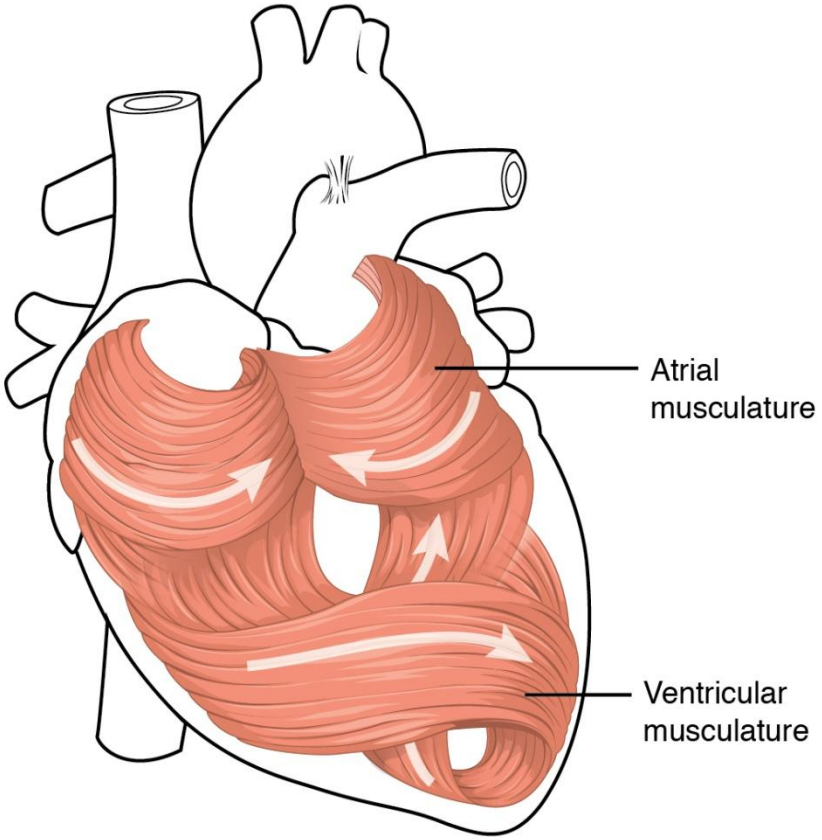
- **Epicardium** lines the outer surface of the heart. It is a serous membrane (visceral layer of serous pericardium).

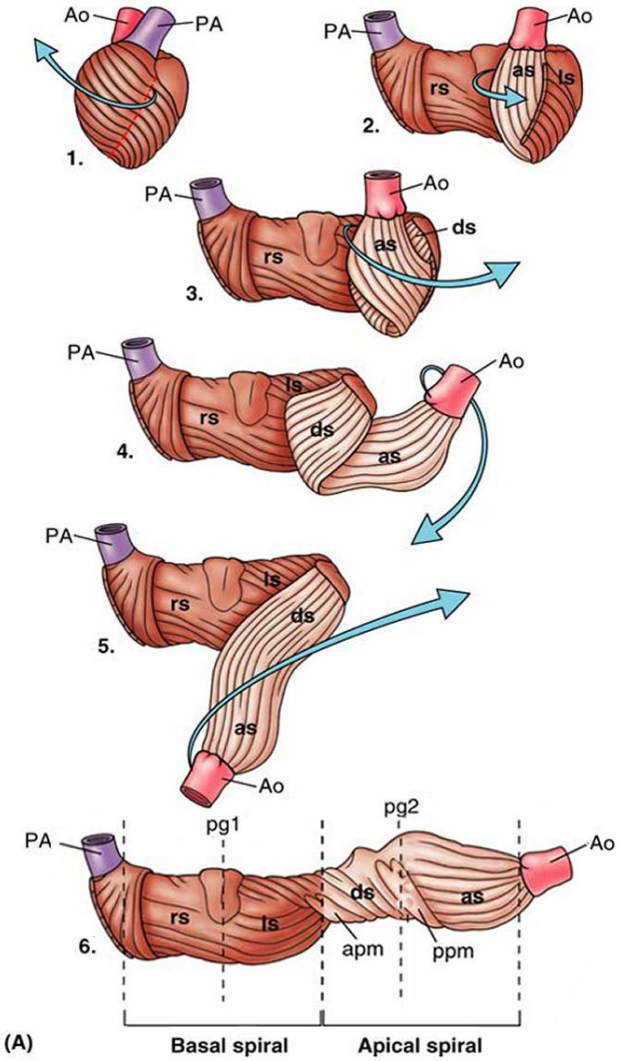
Myocardium

Myocardium of the ventricles (according to F. Torrent-Guasp et al., 2001) has a helical (double spiral) structure. It is made up by:

- an outer **basal spiral,** that comprises outer wall of the right ventricle (right segment) and outer wall of left ventricle (left segment);
- an deeper **apical spiral** which comprises descending and ascending segments.

Myocardium of the ventricles (F. Torrent-Guasp et al.)





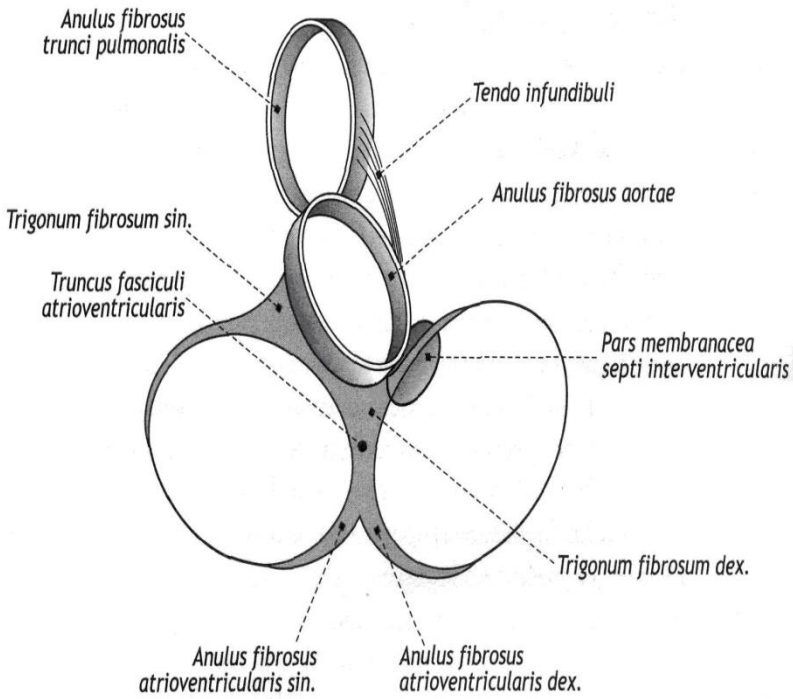
Fibrous skeleton of the heart

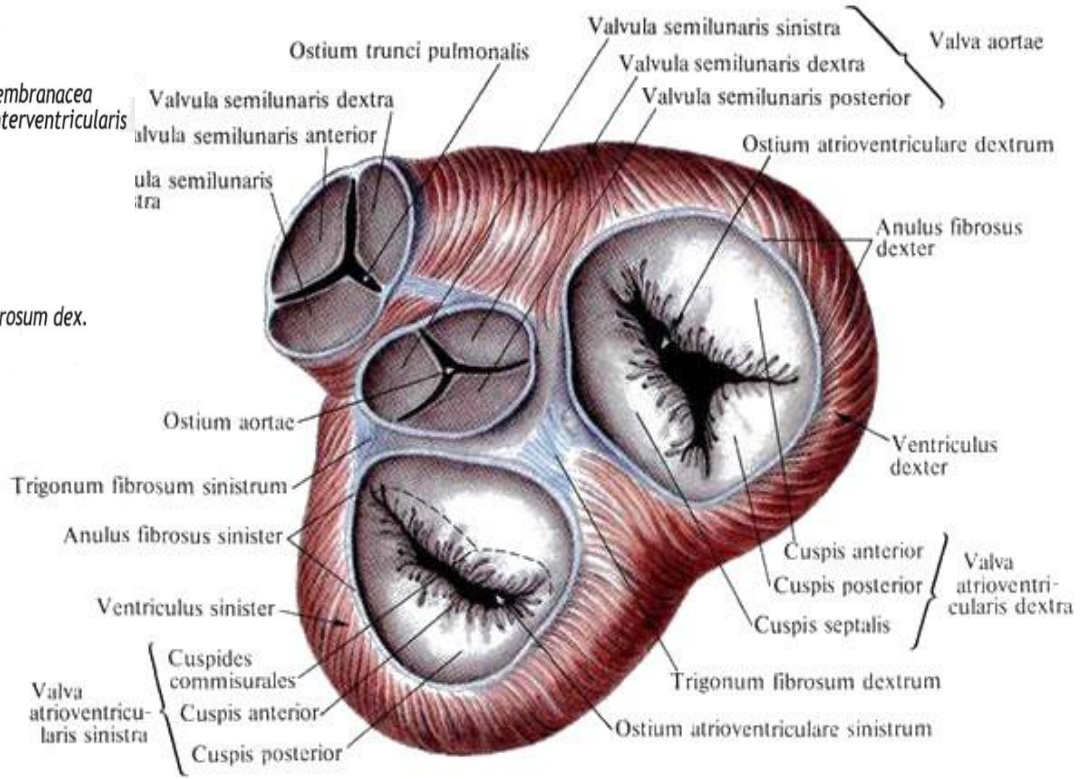
The muscle fibers are anchored to the **fibrous skeleton of the heart**, which consists of:

- four ***fibrous rings*****,** that surround the orifices of the heart;
- **right** and **left fibrous trigones**, formed by connections between the rings.

The fibrous skeleton of the heart separates the myocardium of the atria from the myocardium of the ventricles. The atria can contract separately from the ventricles.

Fibrous skeleton of the heart





Fibrous skeleton of the heart

The **fibrous skeleton** of the heart:

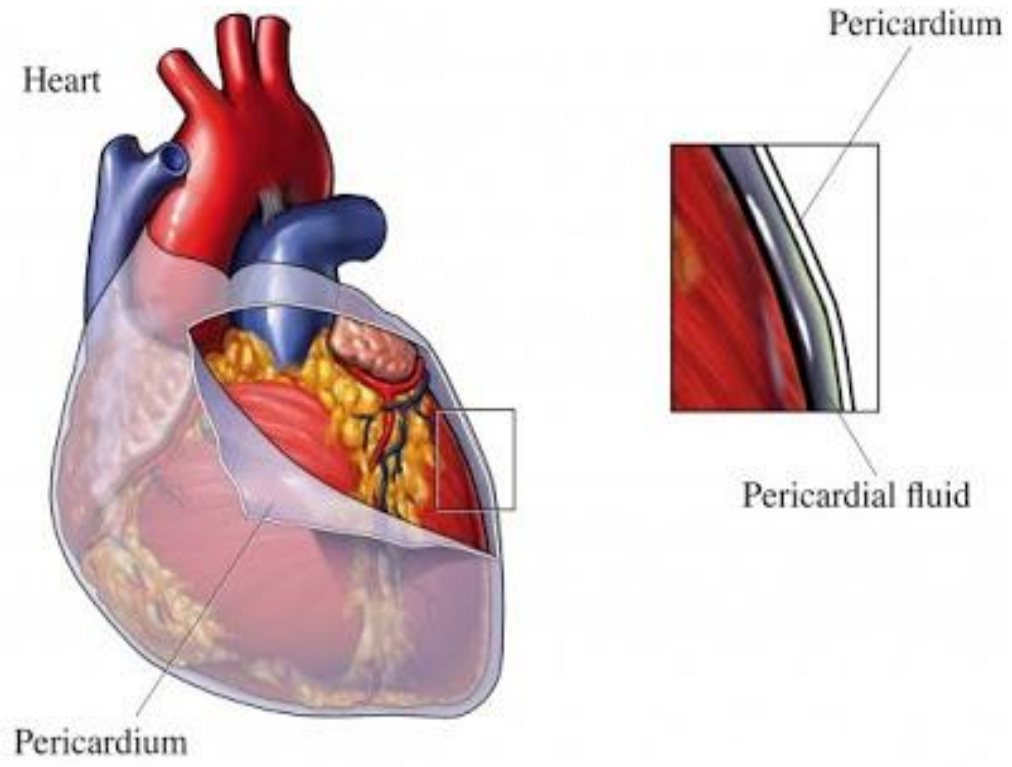
- keeps the AV, aortic and pulmonary orifices patent (maintains their caliber) and prevents them from being overly distended;
- provides attachments for the leaflets or cusps of the valves;
- provides attachment for the myocardium of the atria and myocardium of the ventricles.

Pericardium

The **pericardium** is a fibroserous membrane that covers the heart and the beginning of the great vessels (ascending aorta, pulmonary trunk, superior vena cava). It consists of two layers:

- the outer layer, **fibrous pericardium**;
- the inner layer, **serous pericardium**, which is composed of ***parietal layer*** *of serous pericardium* and ***visceral layer*** *of serous pericardium* (makes up the epicardium).

Pericardium



Pericardium

The **fibrous pericardium** is:

- continuous superiorly with *tunica adventitia* of the great blood vessels entering and leaving the heart;
- attached anteriorly to the posterior surface of the sternum by the ***sternopericardial ligaments*;**
- continuous inferiorly with the central tendon of the diaphragm and constitutes the ***pericardiophrenic ligaments;***
- bounded posteriorly by loose connective tissue to structures in the posterior mediastinum and to the spine by the ***pericardiovertebral ligaments.***

Pericardium

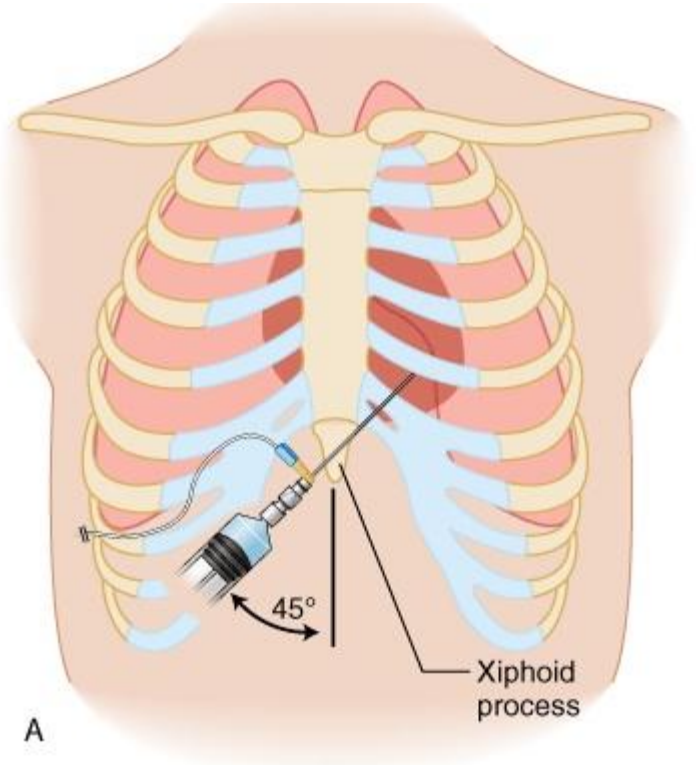
The **pericardial cavity** is the potential space between two layers of the serous pericardium. It normally contains a thin film of fluid that allows the heart to move and beat in the frictionless environment. There are two sinuses of the pericardial cavity:

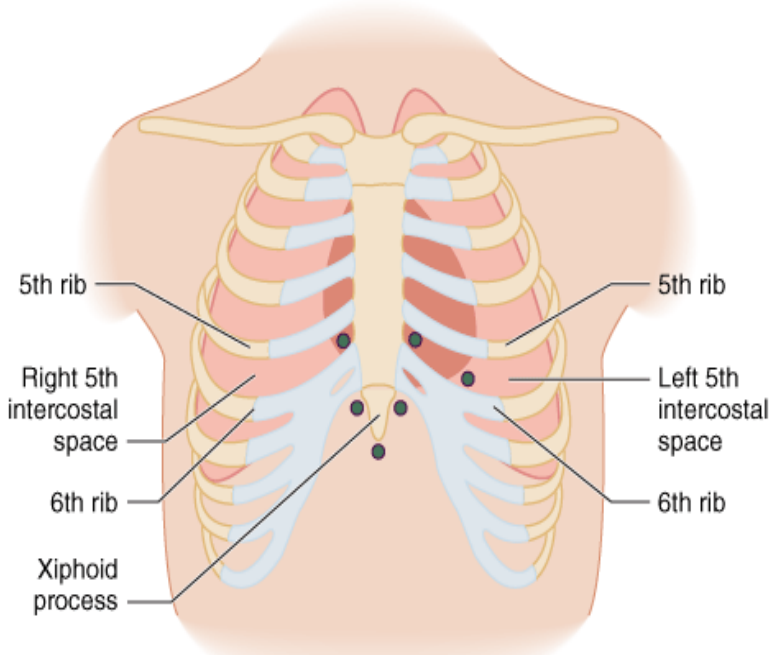
- ***transverse pericardial sinus*** (behind the aorta and pulmonary trunk);
- ***oblique pericardial sinus*** (between the inferior vena cava and left pulmonary veins).

Pericardium

- ***Pericarditis*** – inflammation of the pericardium.
- ***Cardiac tamponade*** – heart compression by an accumulation of fluid in the pericardial cavity; it is a potentially lethal condition.
- ***Pericardiocentesis*** – drainage of the fluid from the pericardial cavity. To remove the excess of fluid, a wide-bore needle may be inserted through the left 5^{th} or 6^{th} intercostal space near the sternum. The pericardial sac may also be reached by entering the infrasternal angle and passing the needle superoposteriorly.

Pericardiocentesis





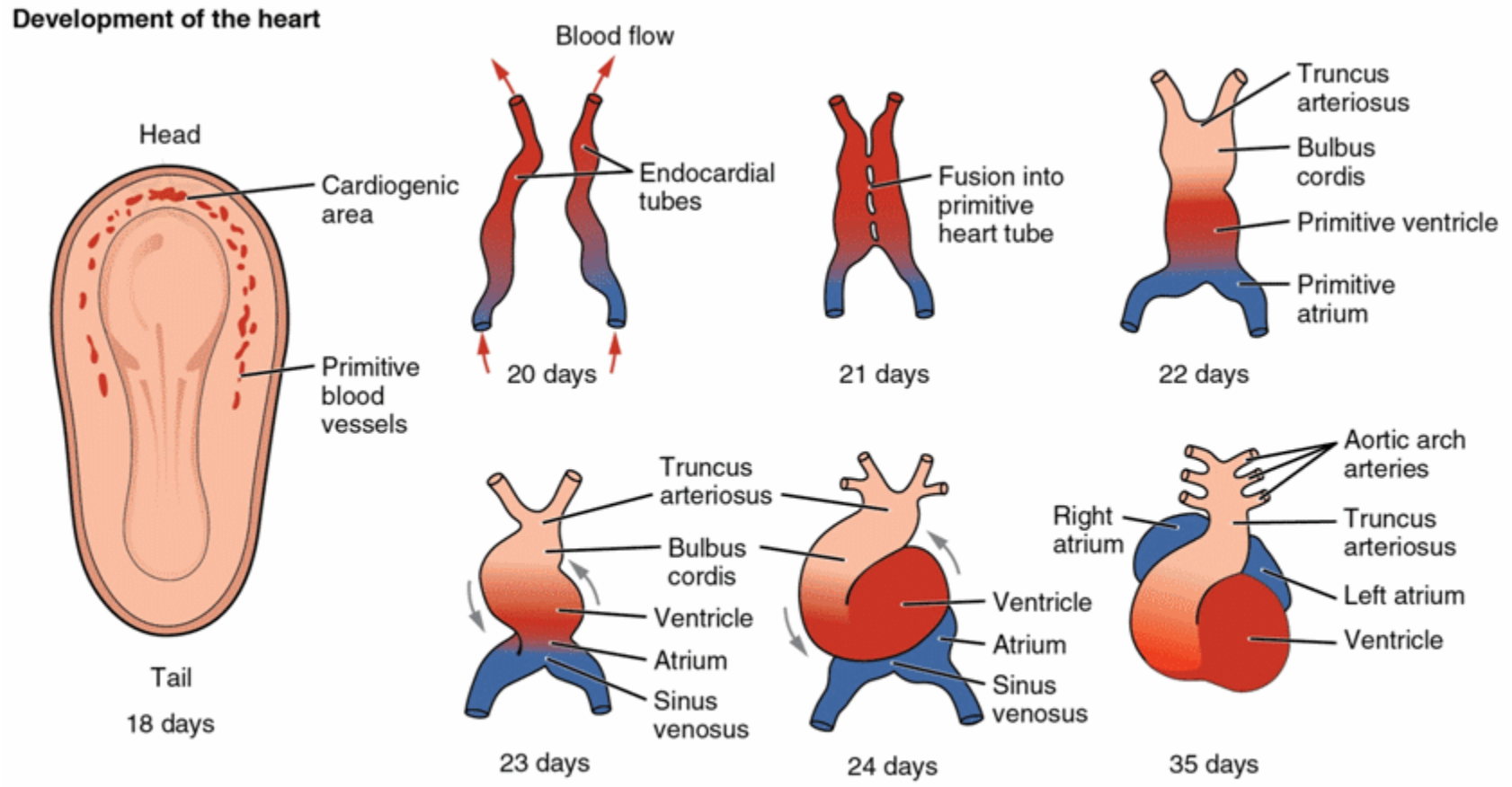
Development of the heart

1. ***Formation of the primitive heart tube*** (or tubular heart);
2. ***Looping of the primitive heart tube***;
3. ***Formation of the cardiac septa***.

1.Formation of the primitive heart tube

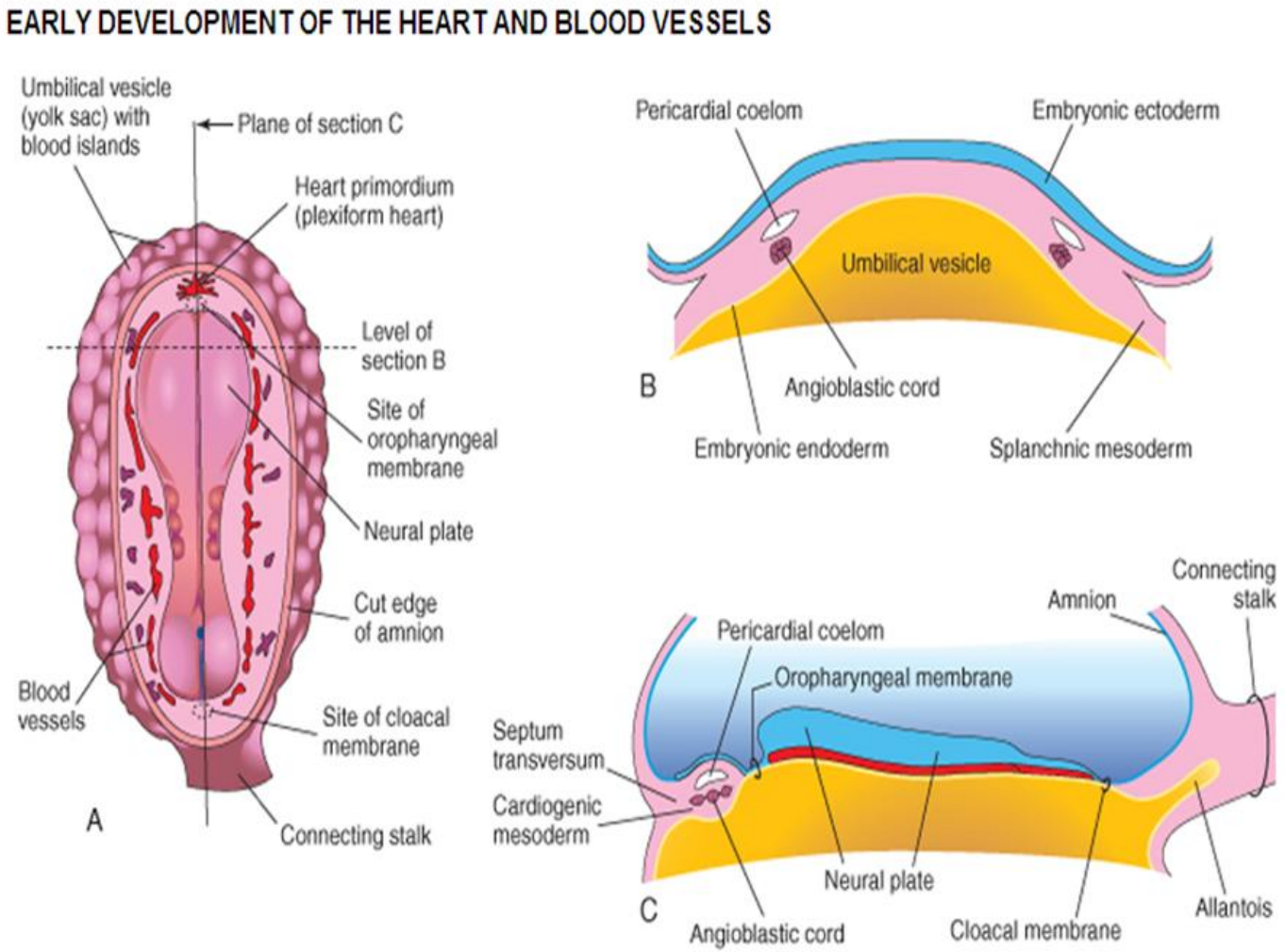
- At around 18 to19 days the heart begins to form. It develops near the head of embryo in the ***cardiogenic area*** (***or field***).
- The cardiogenic area (a horseshoe-shaped area) develops cranially and laterally to the ***neural plate***; its central part is in front of the ***oropharyngeal membrane***.
- The coalescence of the separate *angiogenic cell clusters* forms two ***endocardial tubes***.
- The growth of the brain and the embryonic folding push the endocardial tubes first in the cervical region and then into the thoracic cavity.

Development of the heart



☆Cardiogenic area begins right in the middle of head pole

Cardiogenic area (or field)



1.Formation of the primitive heart tube

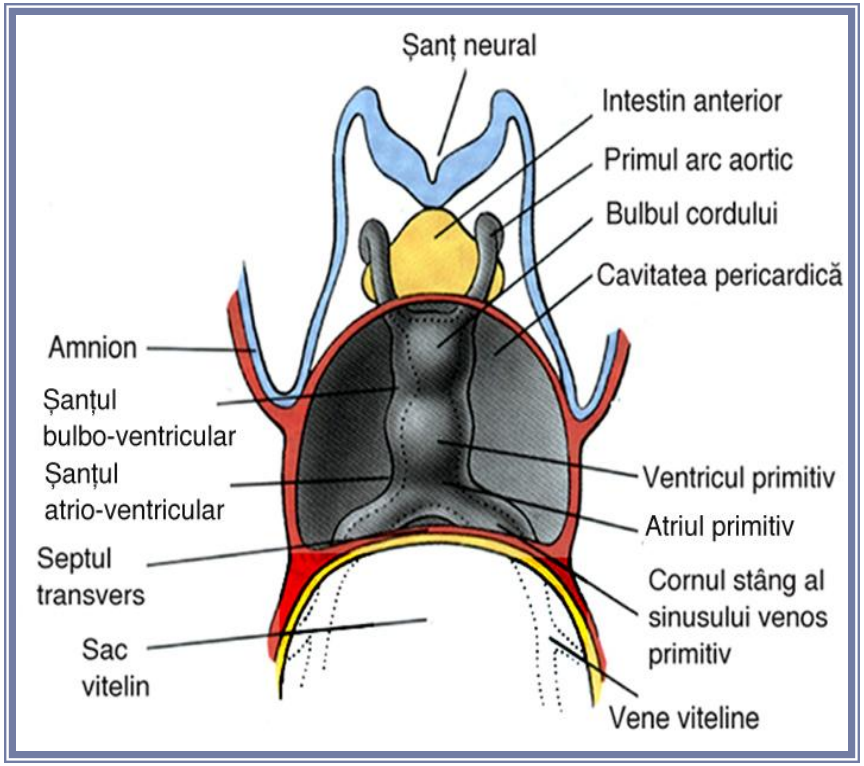
- ***Two endocardial tubes***, pushed in the thoracic cavity, begin to fuse together and this process is completed at about 22 days.
- Two tubes form a single primitive heart tube – the ***tubular heart***, which quickly forms five distinct regions:

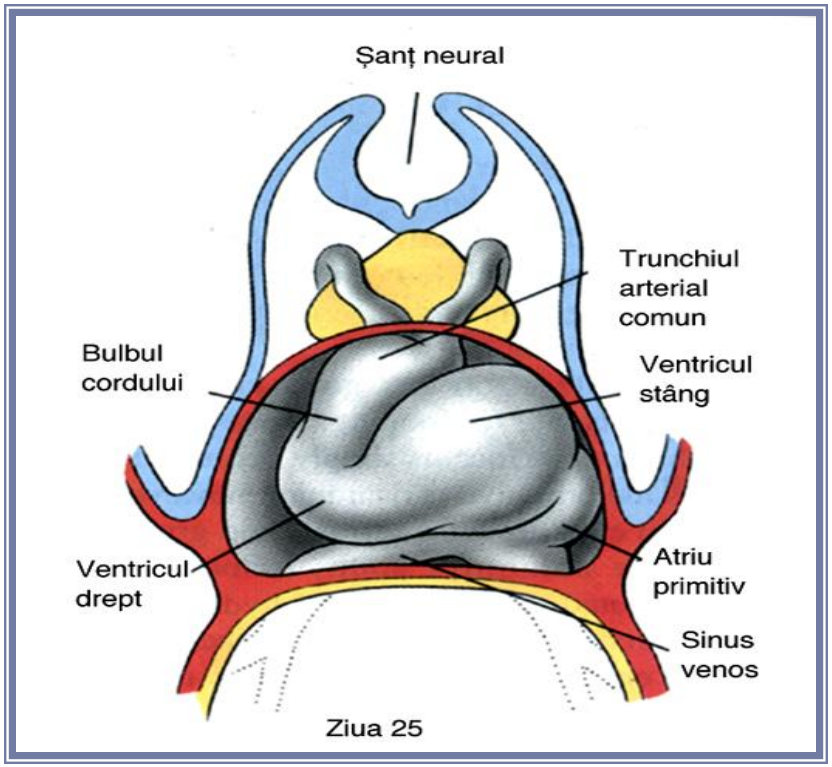
a. ***truncus arteriosus,***
b. ***bulbus cordis,***
c. ***primitive ventricle;***
d. ***primitive atrium,***
e. ***sinus venosus.***

1.Formation of the primitive heart tube

- The ***truncus arteriosus*** will divide to form the *aorta* and the *pulmonary trunk*.
- The ***bulbus cordis*** will develop into the *right ventricle*.
- The ***primitive ventricle*** will form the *left ventricle*.
- The ***primitive atrium*** will become the anterior parts of both *atria* and *auricles*.
- The ***sinus venosus*** will develop into the posterior part of the *right atrium* and the *coronary sinus*.

Development of the heart

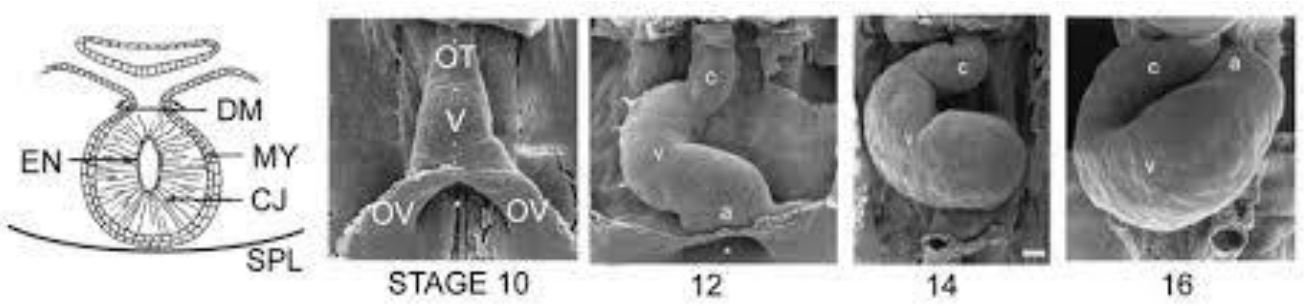


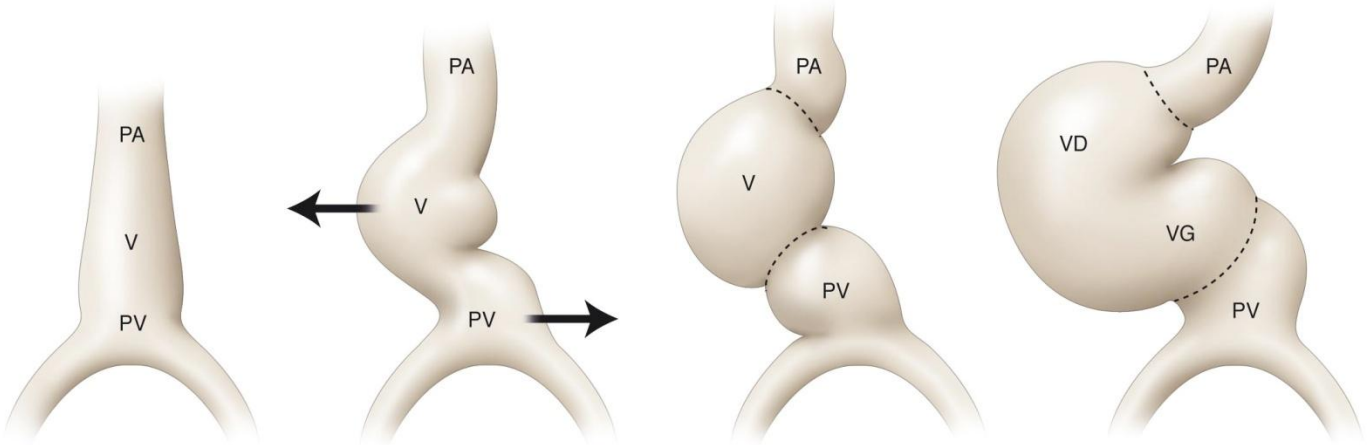


2. Looping of the primitive heart tube

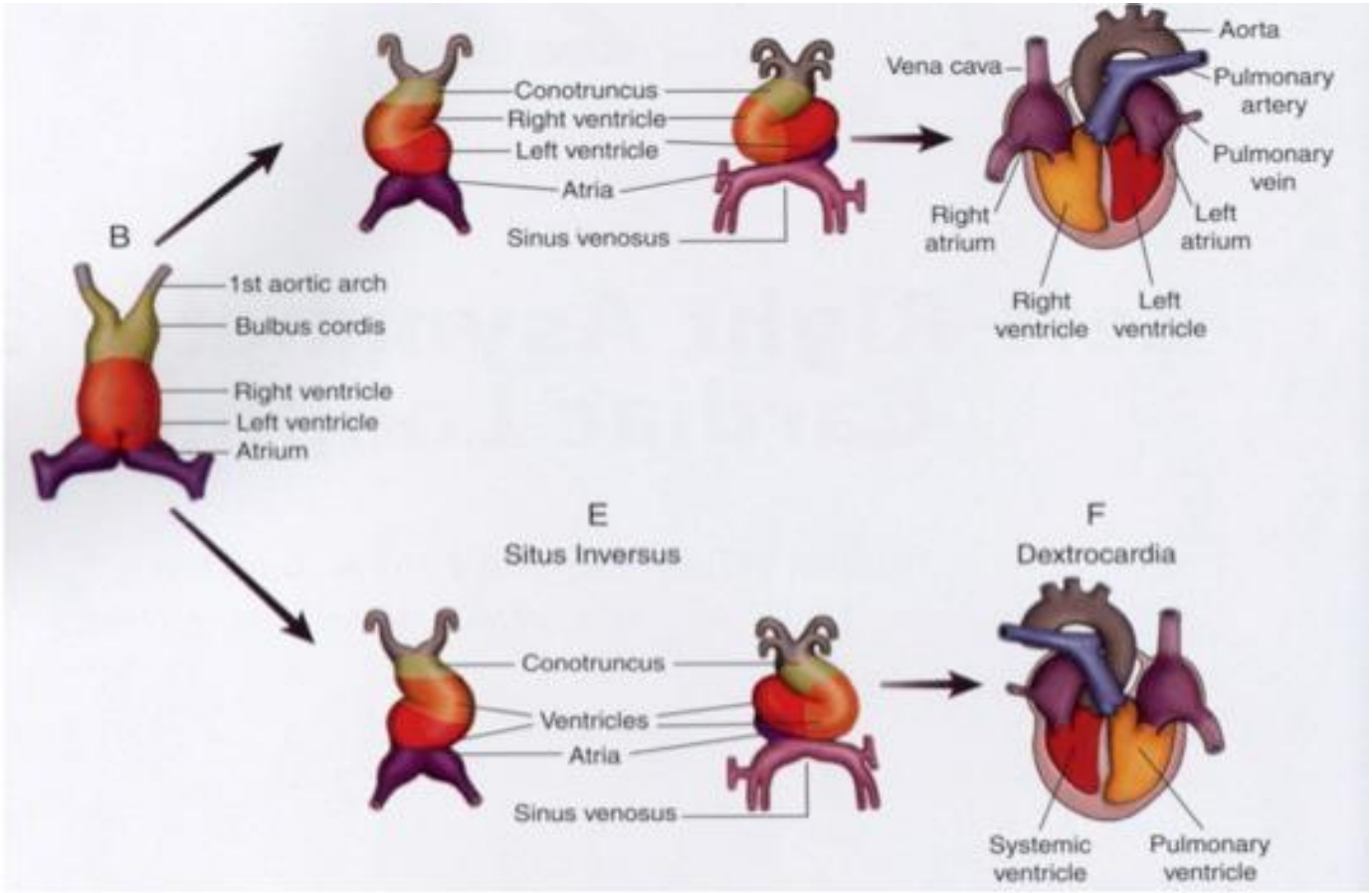
- The heart tube continuous to grow and bend by day of 23 – the cardiac looping begins.
- The heart tube bends and twists (loops): the *cephalic portion* bends ventrally, caudally and to the right, the *caudal portion* bends dorsocranially and to the left. This bending creates the ***cardiac loop***.
- The atrioventricular junction remains narrow and forms the ***atrioventricular canal.***
- The bulbus cordis is narrow except the proximal third (it will form the right ventricle). The distal part of *bulbus cordis*, the ***conus cordis***, will form the outflow tracts of both ventricles.

2. Looping of the primitive heart tube





Abnormalities of cardiac looping: dextrocardia



3. Formation of the cardiac septa

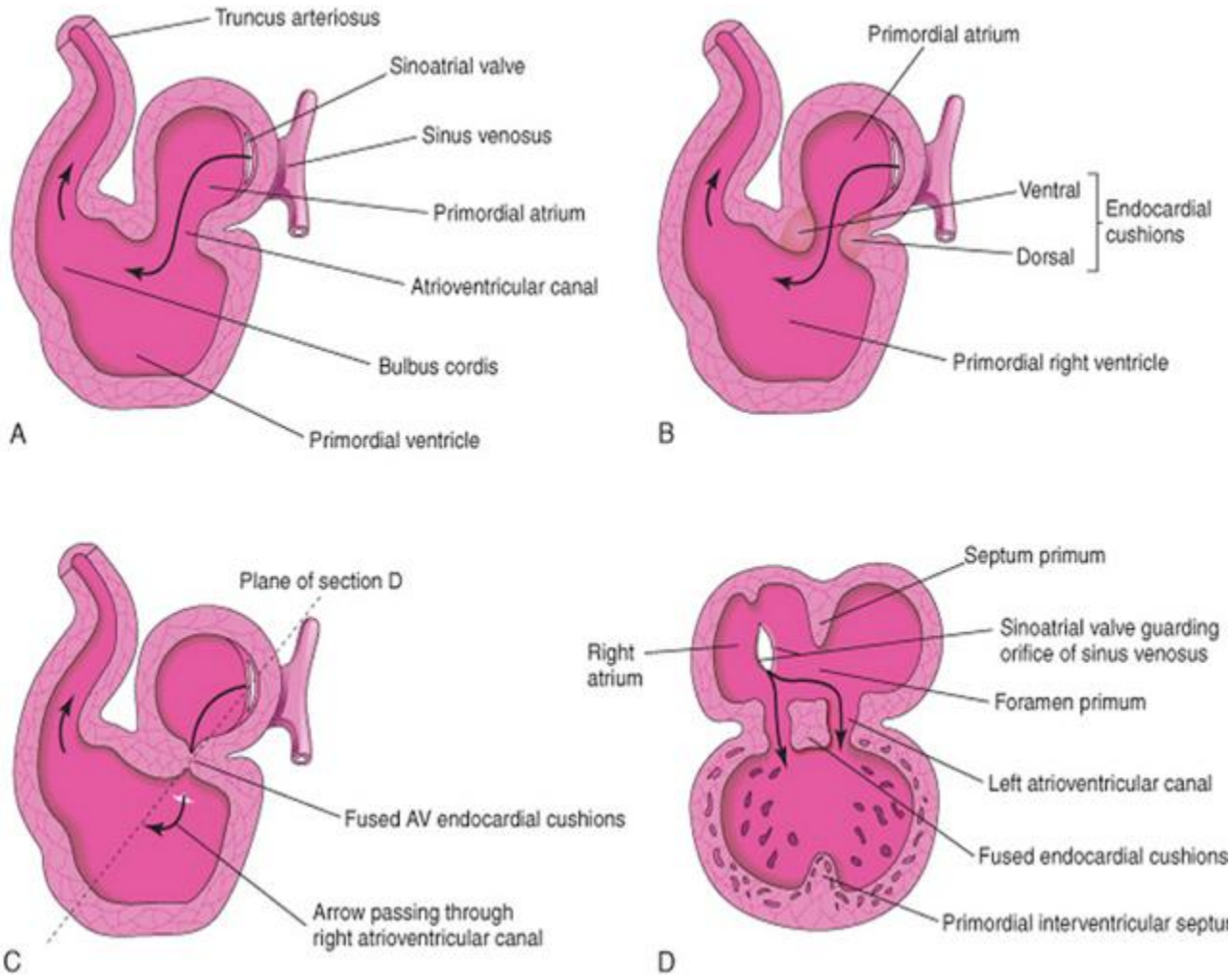
- The ***partition*** of the atrioventricular canal, the atrium, the ventricle and the truncus arteriosus begins about the middle of week 4 and is compete by the end of 5 week (days 27 to 37), when the embryo grows in length from 5 mm to about 16 or 17 mm.
- Although describe separately, the processes take part concurrently.
- Formation of cardiac septa includes:

a. formation of the atrioventricular septum,
b. formation of the interatrial septum,
c. formation of the interventricular septum,
d. formation of the aorticopulmonary septum.

a. Atrioventricular canal septation

- On the ventral and dorsal walls of the canal appear ***two endocardial cushions***, which move toward to each other and finally fuse (between days 35 and 40) to form ***primitive interventricular septum*** (or AV septum).
- By day 40, the atrioventricular canal is divided into ***right*** and ***left atrioventricular canals***.
- The mesenchyme around each canal proliferates and forms the ***atrioventricular valves*** (*mitral valve* at left and *tricuspid valve* at right).

a. Atrioventricular canal septation



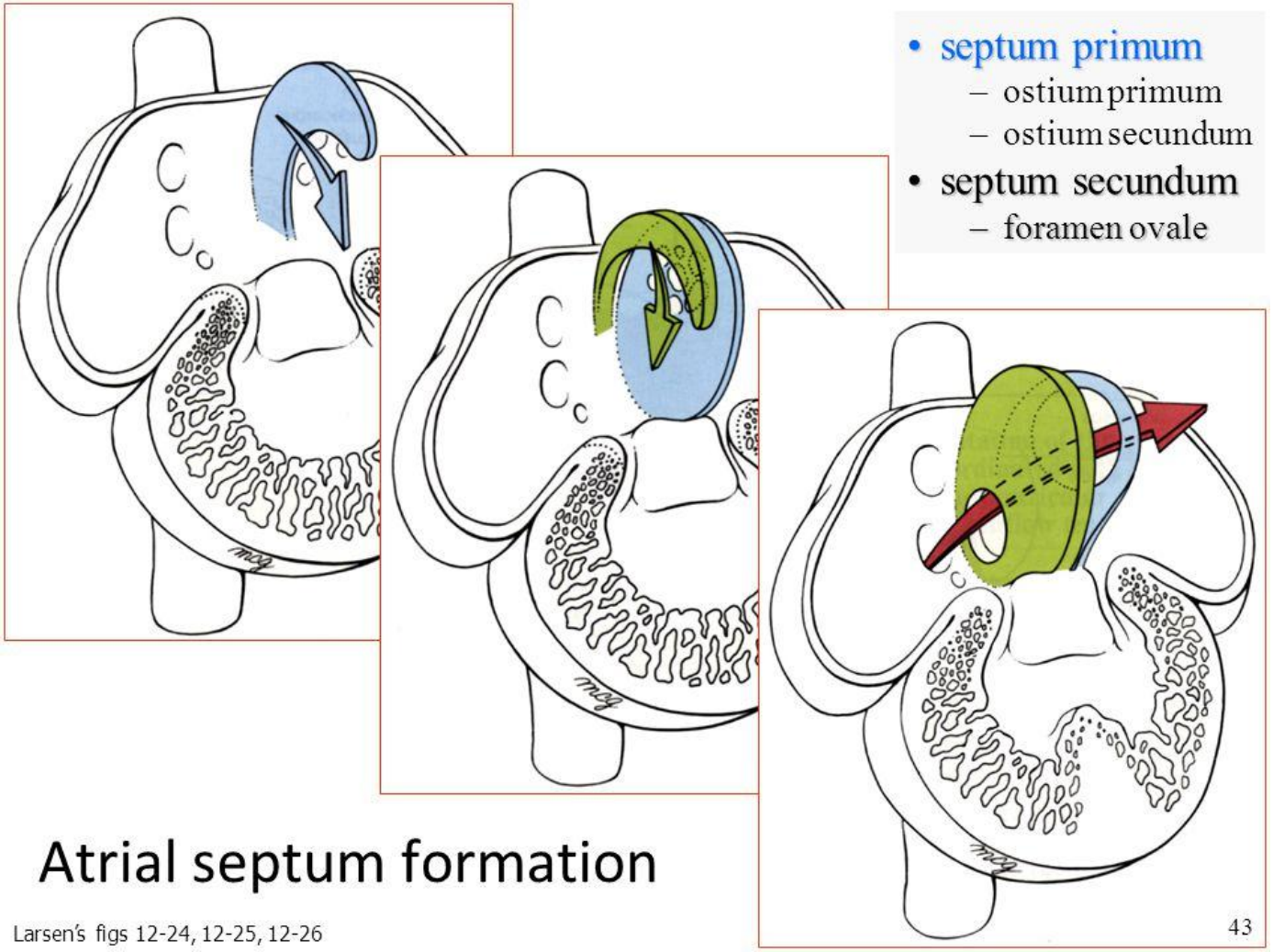
b. Septation of atria

- The ***interatrial septation*** begins during week 5.
- The ***septum primum*** appears on the superior wall of the primitive atrium and grows towards the endocardial cushions. A large, temporary opening exists between the *septum primum* and the endocardial cushions called the ***foramen (ostium) primum***, which rapidly gets smaller.
- Before closure of the foramen primum, small openings or perforations appear in the upper part of the septum primum, which merge to form another opening, the ***foramen (ostium) secundum.***

b. Septation of atria

- A new membrane appears to the right of the *septum primum* on the superior wall of the atrium near the end of week 5. It grows towards the endocardial cushions as the ***septum secundum***.
- The *septum secundum* covers the foramen secundum of the septum primum, but remains an oval-shaped passageway, the ***foramen ovale***.
- Complete fusion of the septum primum to the septum secundum forms the definitive ***interatrial septum***, obliterating the foramen ovale.

b. Septation of atria



Development of the atria

- **The right atrium**

a. The ***sinus venarum*** (the smooth-walled part of the right atrium into which the great veins open) is derived from the *sinus venosum*.

b. The rest of the atrium and the auricle have a rough trabeculated surface and are derived from the *primitive atrium*.

- **The left atrium**

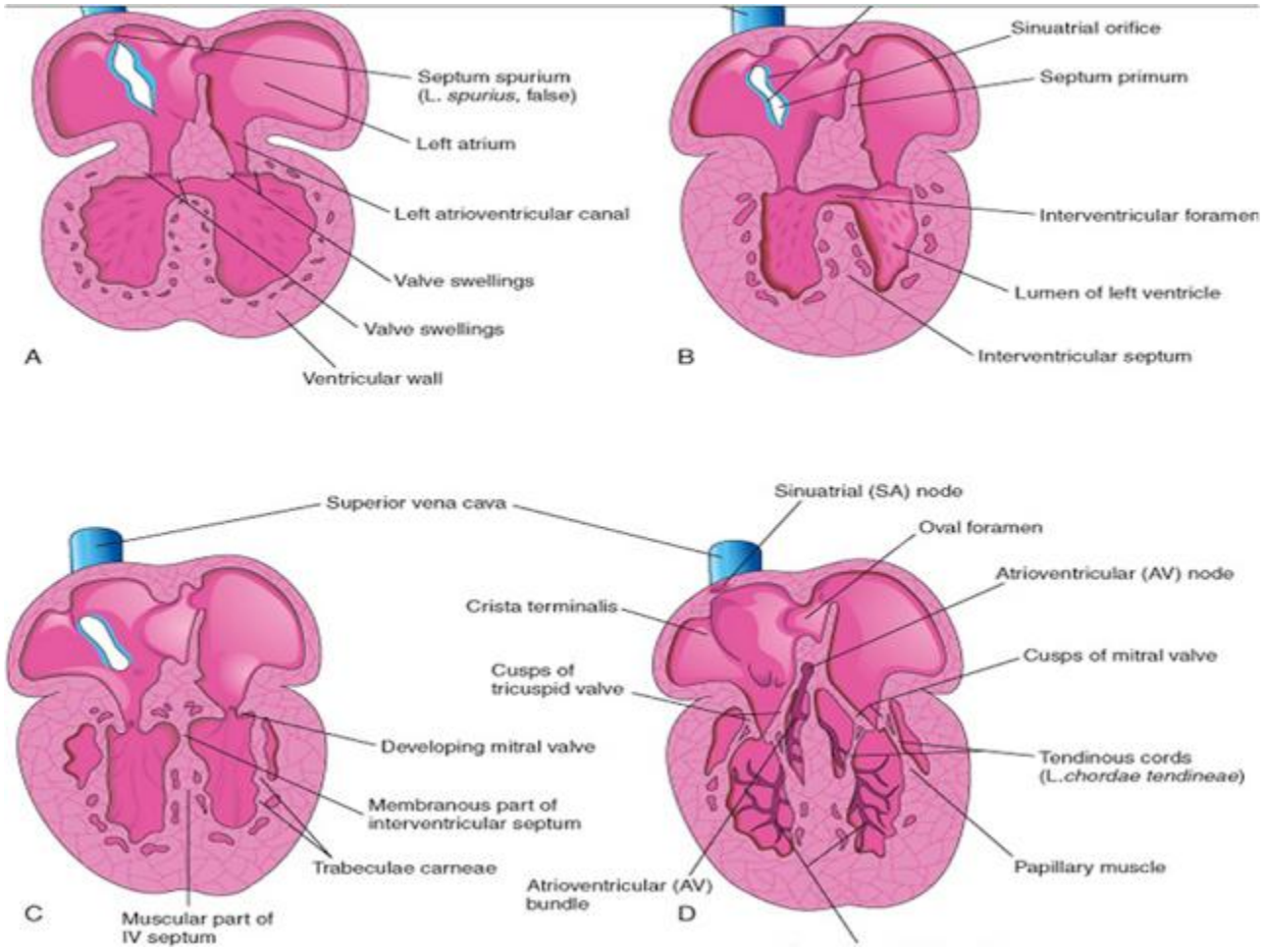
a. Most of the left atrium is smooth and is derived from the *primitive pulmonary vein*, which is absorbed into the wall of the atrium.

b. Only the left auricle has a rough, trabeculated appearance and is derived from the *primitive atrium*.

c. Septation of ventricles

- A muscular crest (ridge or fold) appears on the inferior ventricular wall, at the same time that the interatrial septum is forming, at about week 5. This is the ***interventricular septum primordium***.
- This septum forms the ***muscular portion*** *of the interventricular septum.*
- The septum is incomplete. *A* ***interventricular foramen*** is seen between the septum and the fused endocardial cushions, which allows the communication between the ventricles until about the week 7.

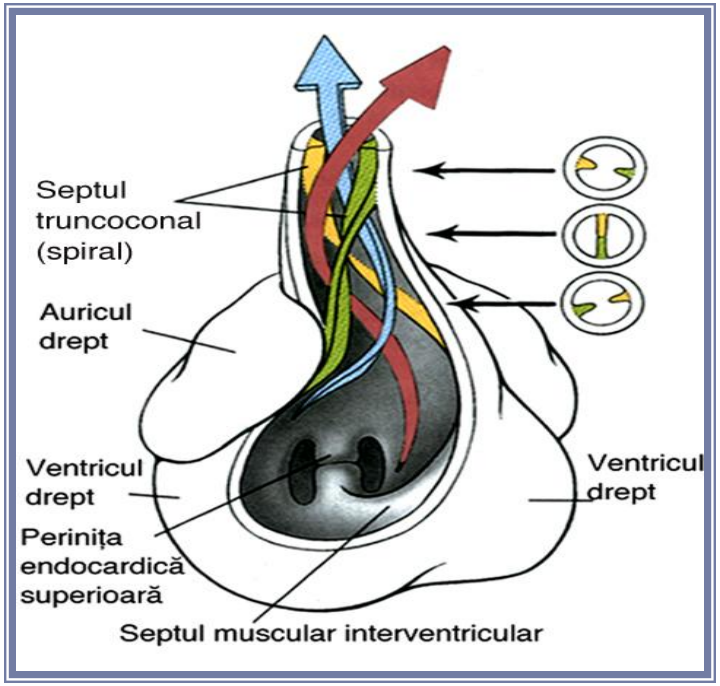
c. Septation of ventricles

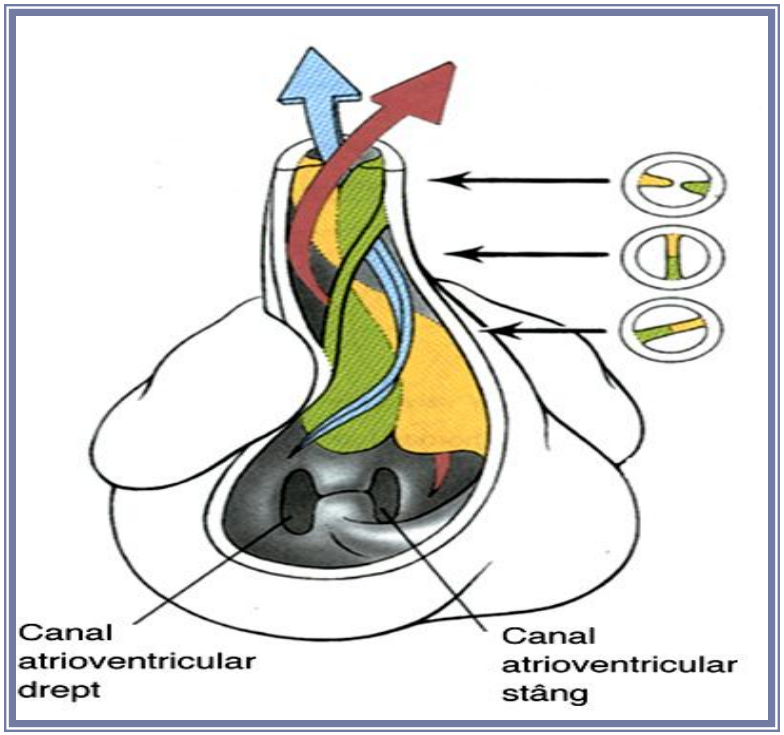


d. Septation of truncus arteriosus and conus cordis

- The subendocardial tissue in the conus cordis thickens into two ridges called ***truncoconal*** or ***bulbar ridges***.
- Two ***semilunar ridges*** also form in the truncus arteriosus.
- The bulbar ridges soon fuse with the ridges of the truncus arteriosus. The fusion takes a spiral orientation and forms the ***aorticopulmonary septum*** (or the conotruncal septum), which separates the aorta and the pulmonary trunk, and the outflow tracts of both ventricles (the ***conus arteriosus*** or *infundibulum* of the right ventricle and the ***aortic vestibule*** of the left ventricle).

d. Septation of truncus arteriosus and conus cordis

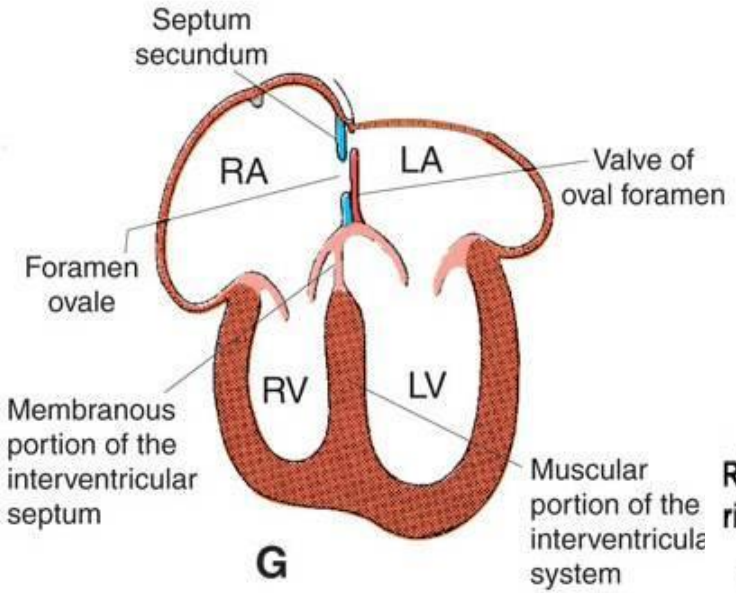


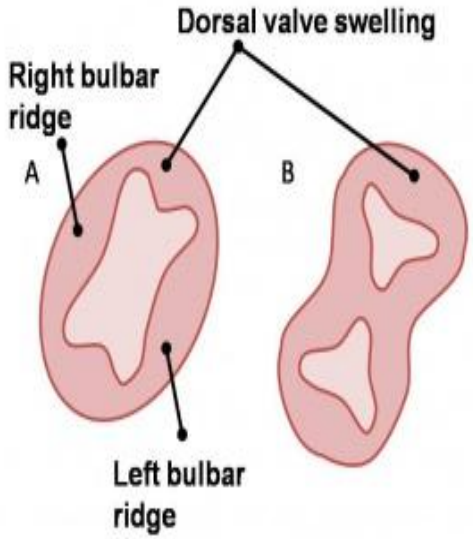


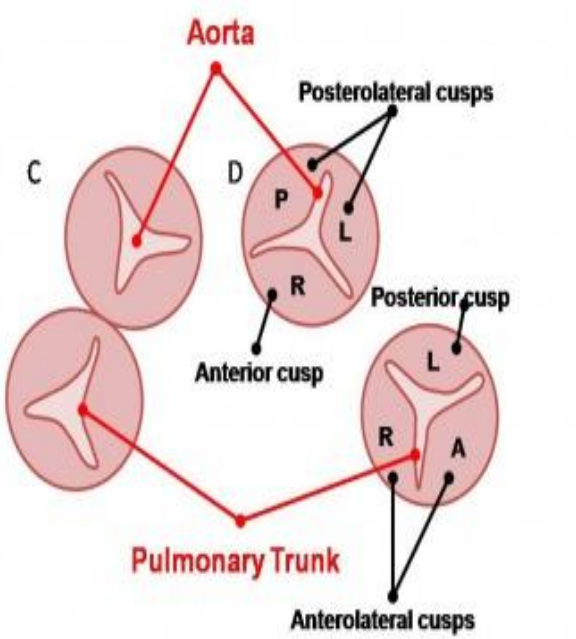
c. Septation of ventricles

- Ventricular septation is completed by closure of the ***interventricular*** communication (***foramen***) around the end of week 7, as the bulbar ridges fuse with the endocardial cushions.
- Fusion of the *bulbar ridges* and the *endocardial cushions* forms the ***membranous portion of the interventricular septum.***
- When partition of the truncus arteriosus is almost complete primordia of the ***semilunar valves*** become visible as small tubercles. Recent evidence shows that neural crest cells contribute to formation of these valves.

Development of semilunar valves



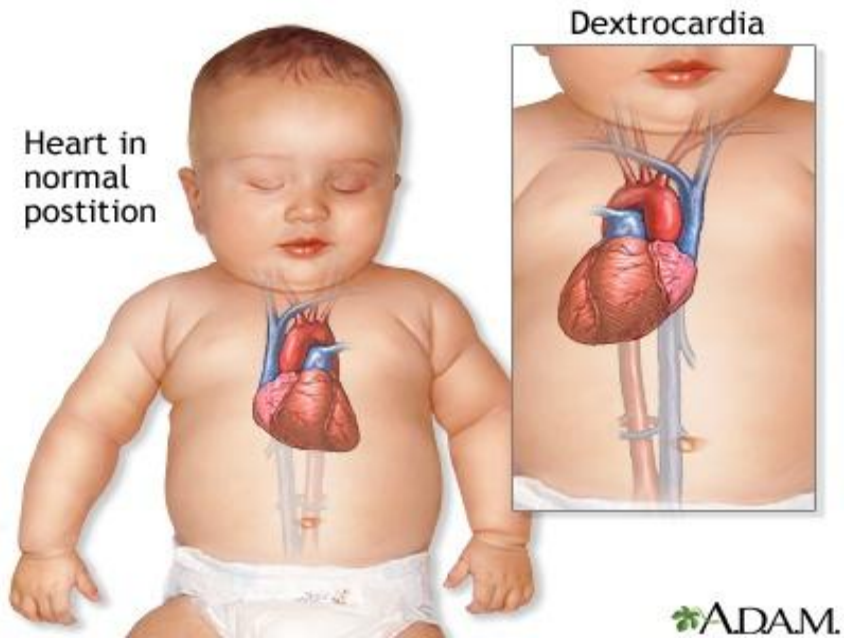




Positional abnormalities of the heart

- ***Dextrocardia*** may be a part of a general transposition of the thoracic and abdominal viscera (*situs viscerus inversus*); the incidence of accompanying cardiac defects is low.
- ***Isolated dextrocardia*** is complicated by severe cardiac anomalies.

Dextrocardia



Ectopia cordis

Ectopia cordis is a congenital malformation in which the heart is abnormally located. According to location of the ectopic heart it is classified in:

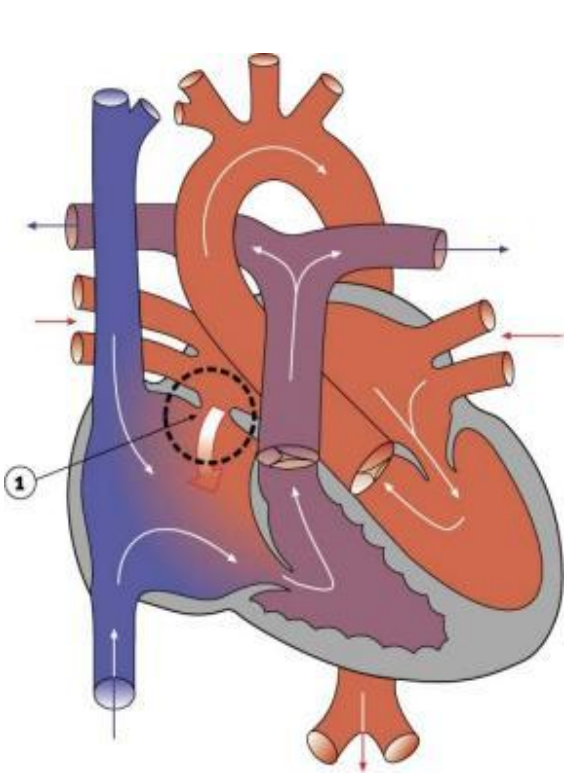
- ***cervical ectopia;***
- ***thoracic ectopia;***
- ***thoracoabdominal ectopia;***
- ***abdominal ectopia.***

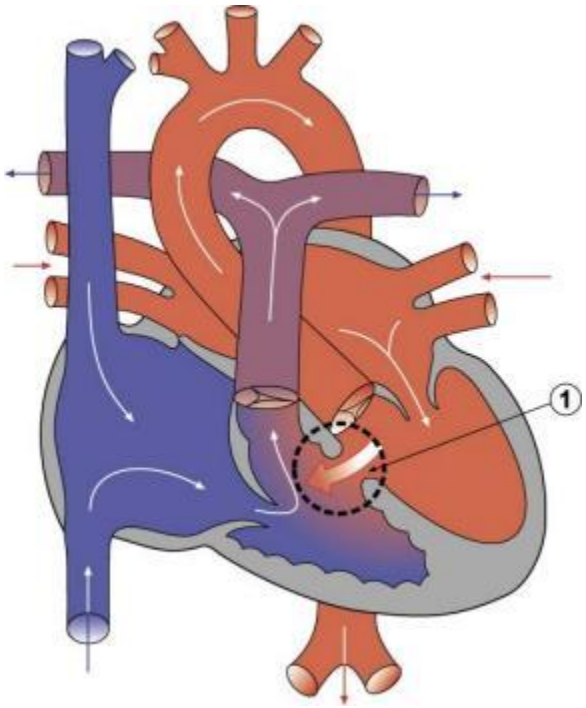
Thoracic ectopia cordis

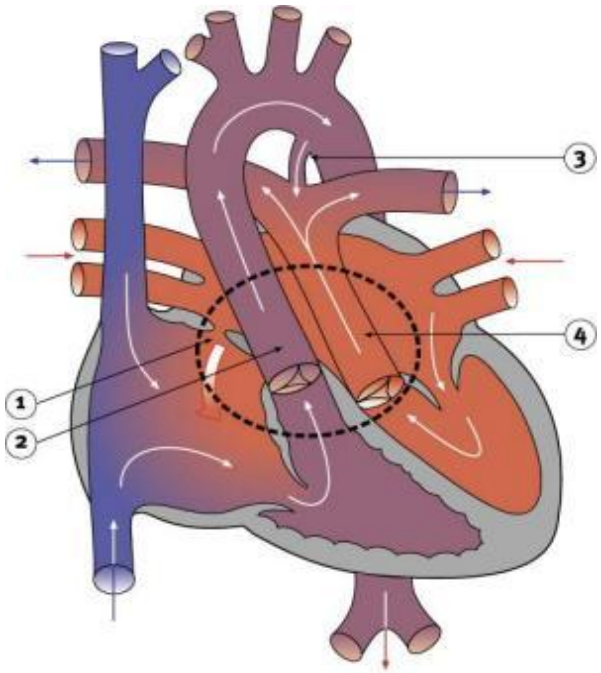
Septal defects (holes in the heart)

- ***Atrial septal defects*** – an opening exists between the atria (e.g. patent *foramen ovale*, *foramen primum defect*, *foramen secundum defect*).
- ***Ventricular septal defects –*** an opening exists between the ventricles (in the membranous or in the muscular portions of the interventricular septum).
- ***Transposition of the great arteries*** – the position of the aorta and the pulmonary trunk are reversed.
- ***Common arterial trunk*** – a single great vessel arises from both ventricles.

Septal defects



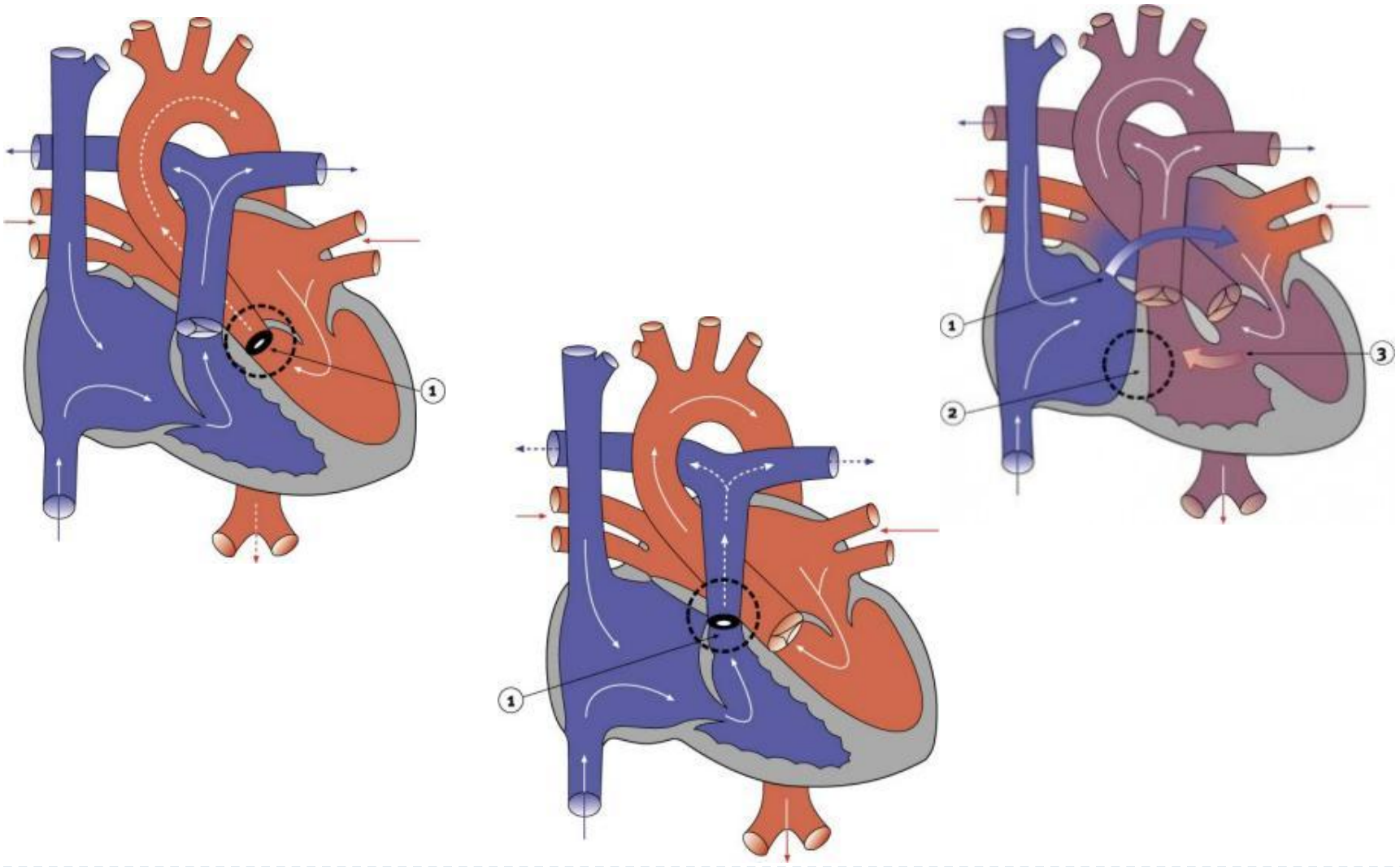




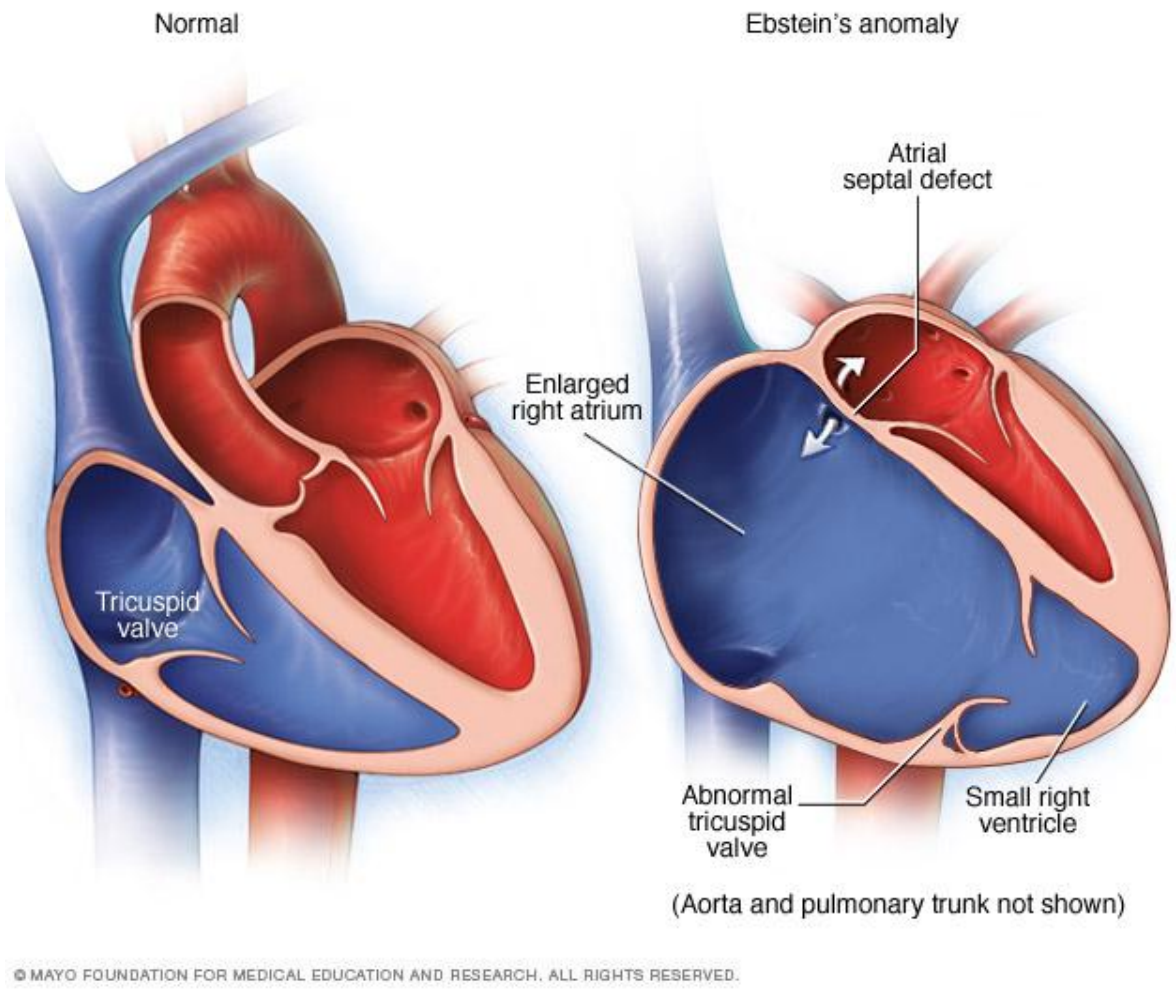
Heart valve defects

- ***Aortic valve stenosis –*** aorta becomes narrowed (stenosis is a narrowing, that partly blocks the flow of blood).
- ***Pulmonary valve stenosis*** – the valve cusps are fused forming a dome with a narrow central opening.
- ***Aortic atresia*** – the aortic valve is closed.
- ***Pulmonary atresia*** – the pulmonary valve is closed (atresia is an obstruction, that completely blocks the flow of blood).
- ***Tricuspid atresia*** – there is no opening between right chambers of the heart.
- ***Ebstein`s anomaly*** – the tricuspid valve has a lower position (the ventricle is too small, the atruim is too large).

Stenosis and atresia



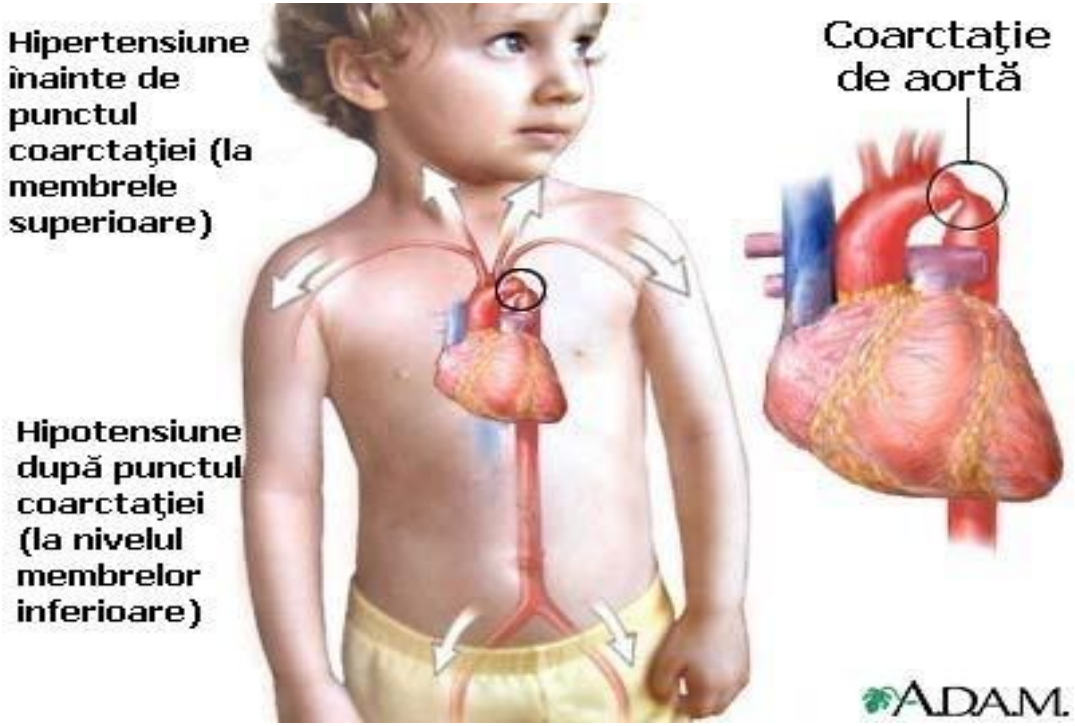
Ebstein`s anomaly



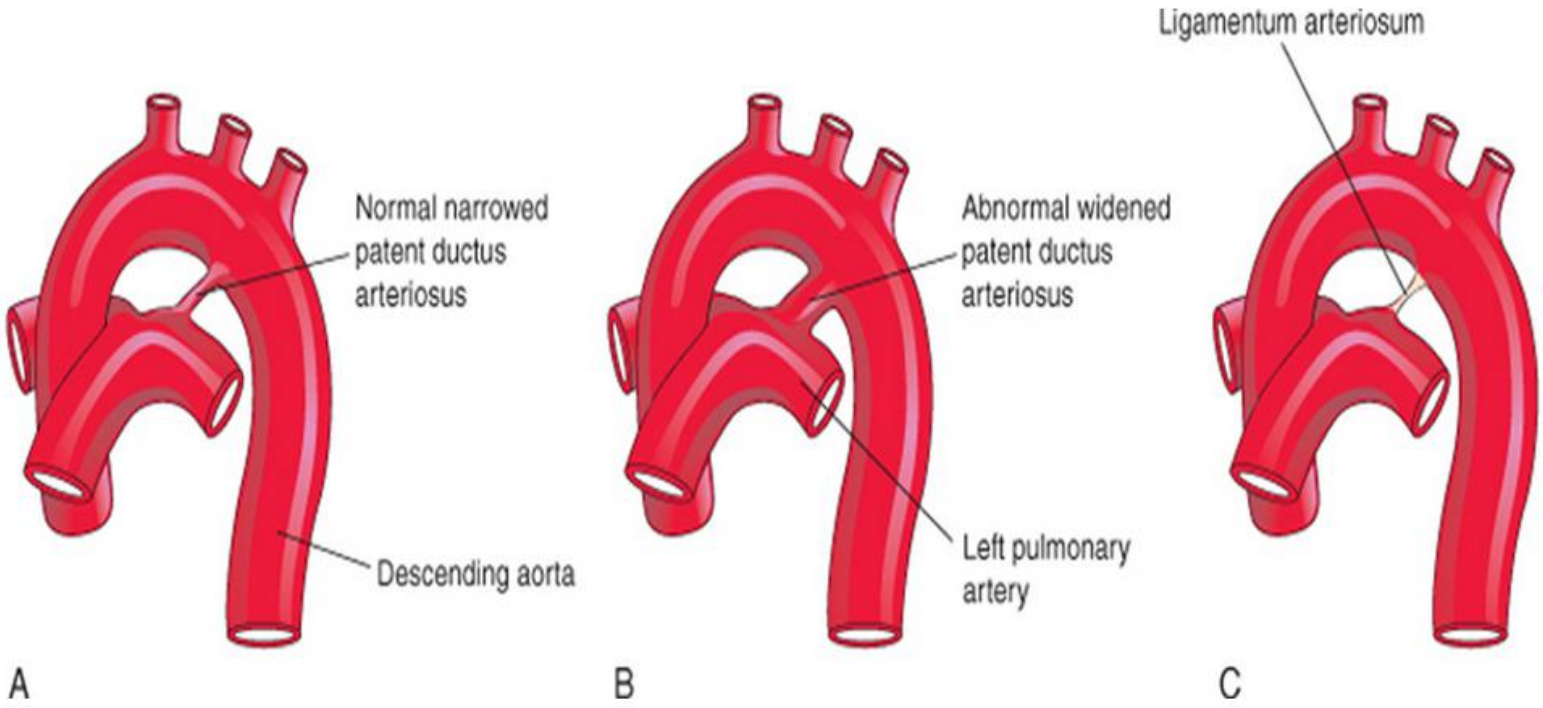
Variations of the great arteries

- ***Coarctation of the aorta*** – the aortic arch or descending aorta has an abnormal narrowing (stenosis), that produces an obstruction to blood flow to the inferior part of the body.
- ***Double arch of the aorta*** forms a vascular ring around the oesophagus and trachea. A trachea that is compressed enough to affect breathing require surgical treatment.
- ***Patent ductus arteriosus***. The ductus arteriosus, a blood passageway that normally closes after birth, fails to close properly (it is a communication between the pulmonary trunk and the aortic arch).

Coarctation of the aorta



Patent ductus arteriosus

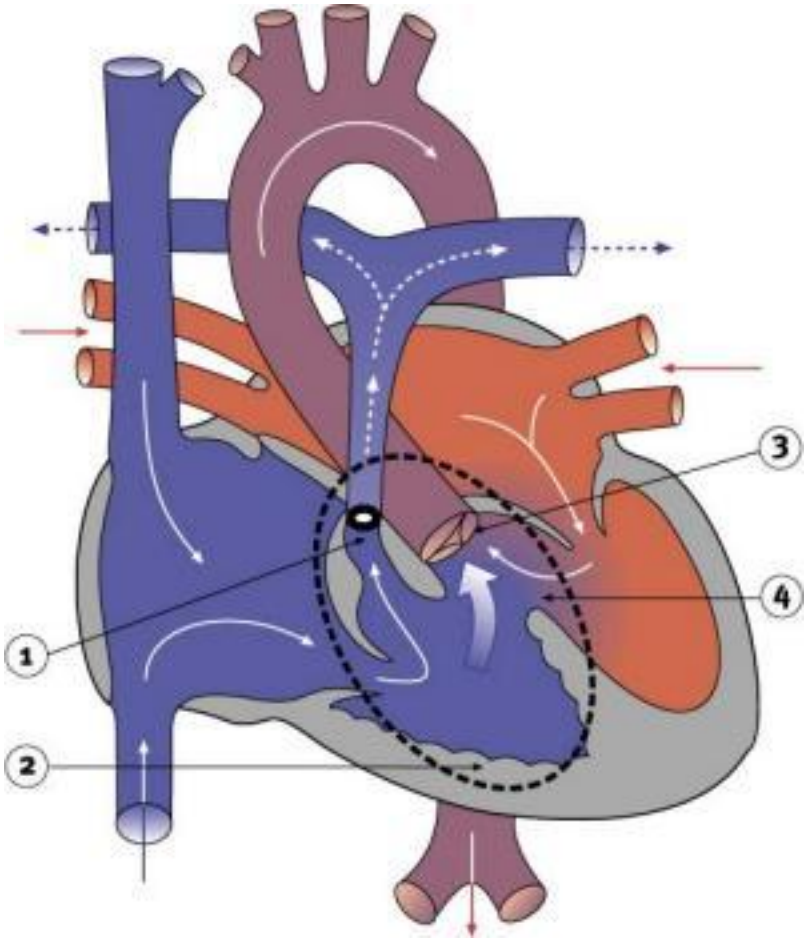


Tetralogy of Fallot

- **Tetralogy of Fallot** (named after Etienne-Louis Arthur Fallot (1888) who described it as "la maladie blue") includes:

a. ***ventricular septal defect;***
b. ***pulmonary valve stenosis***;
c. thickening of the wall (***hypertrophy***) ***of the right ventricle;***
d. ***dextroposition of aorta***.

Tetralogy of Fallot



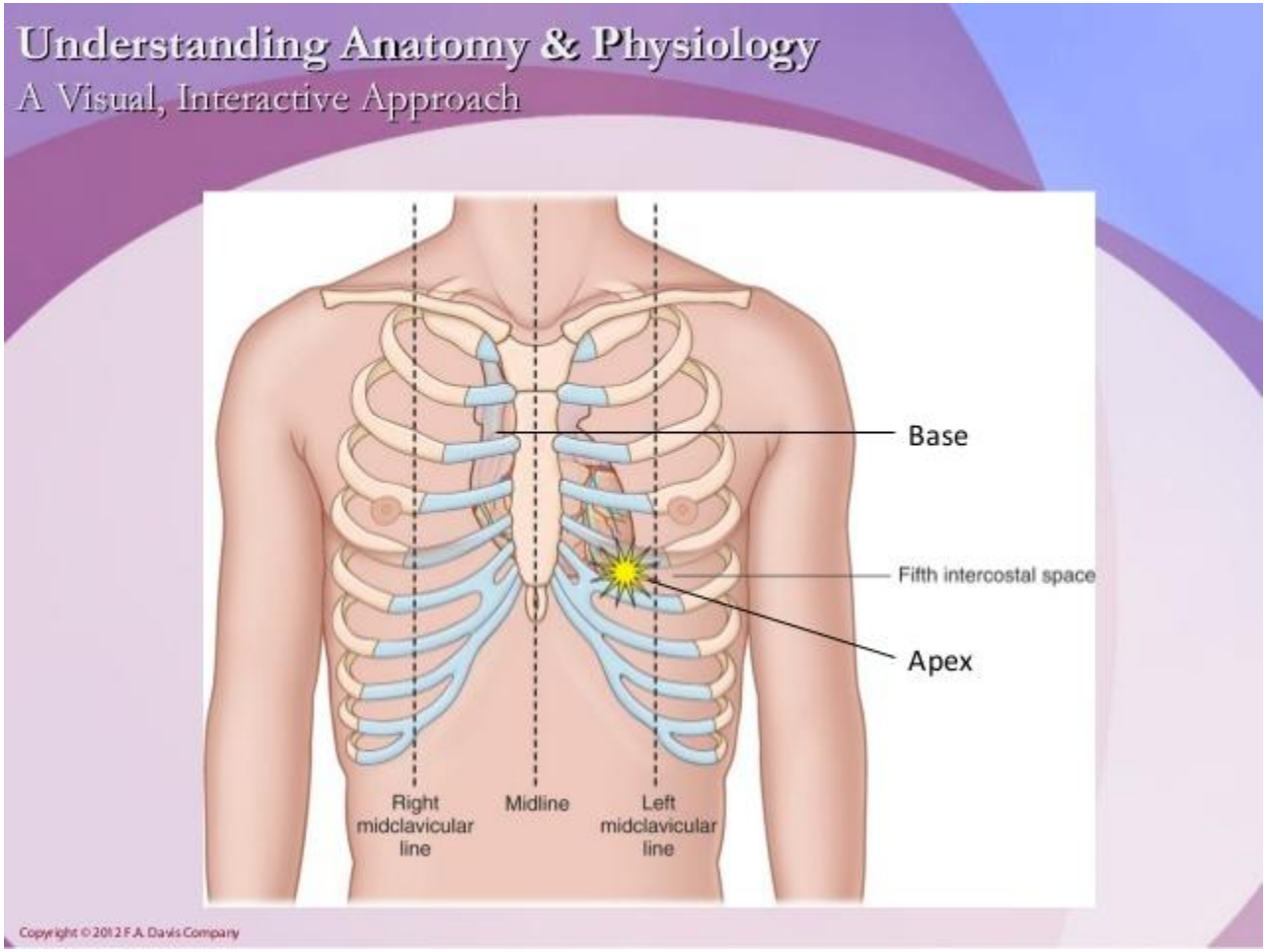
Clinical methods of examination

- ***Inspection*** of visible pulsations***;***
- ***Palpation*** of the apex beat;
- ***Percussion*** of the heart define the density and size of the heart;
- ***Auscultation*** is performed over five locations on the anterior thoracic wall**.**

Surface anatomy of the heart

- The ***apex beat*** is the impulse that results from the apex of the heart being forced against the anterior thoracic wall when the left ventricle contracts. The apex beat is found in the *left 5th intercostal space 8-9 cm laterally from anterior midline* (or *1-1.5 cm medially from left midclavicular line*).

Palpation of the apex beat

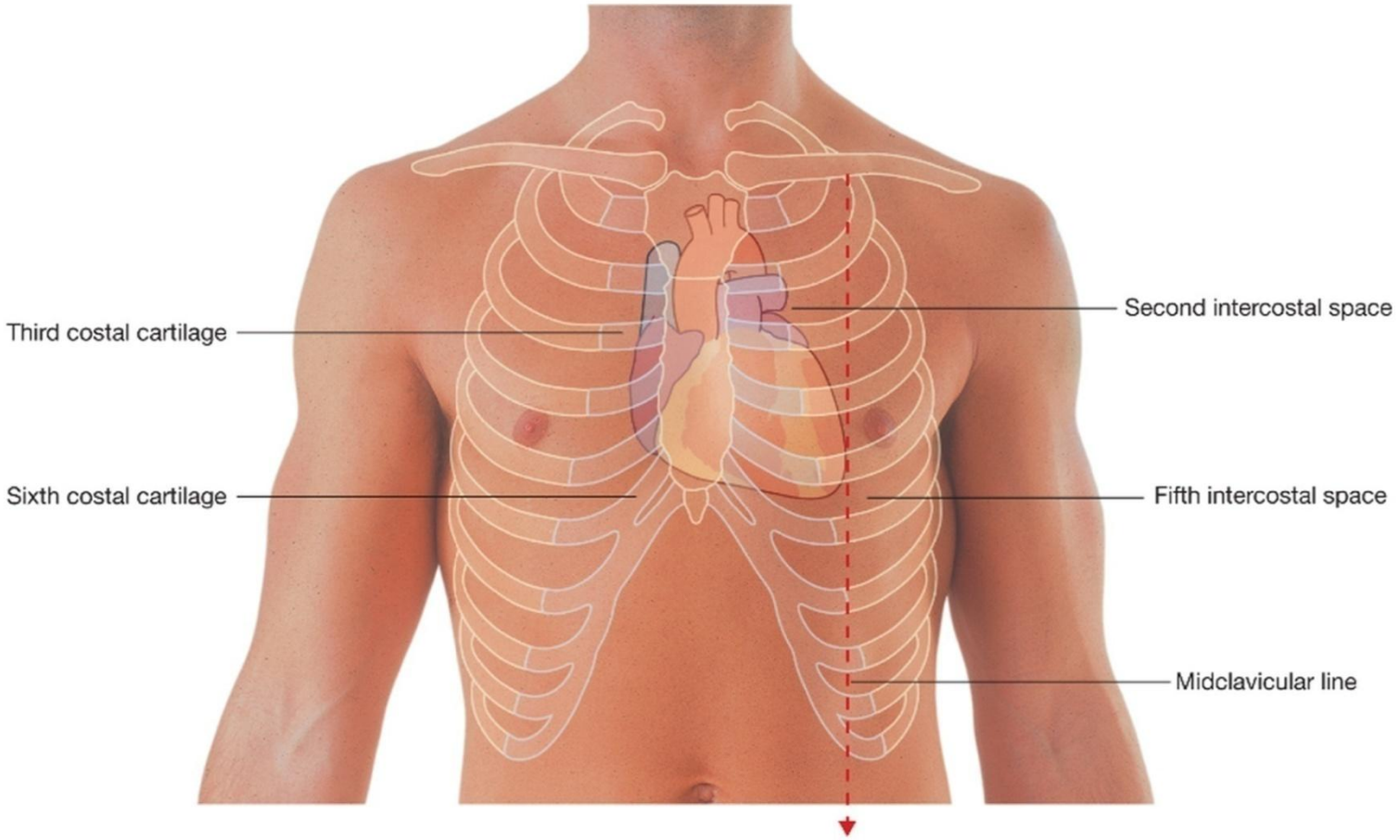


Surface projections of the heart

- **Borders of the heart:**

1. ***The superior border*** is a convex line that runs from superior border of the 3rd left costal cartilage to the superior border of the 3rd right costal cartilage.
2. ***The right border*** is a convex line that runs from the 3rd right costal cartilage to the 5th right costal cartilage (2-3 cm to the right of the right sternal border).
3. ***The inferior border*** is a convex line that runs from the 5th right costal cartilage to the 5th intercostal space close to the left midclavicular line.
4. ***The left border*** is a convex line that runs from the 5th intercostal space close to the left midclavicular line to the superior border of the 3rd left costal cartilage.

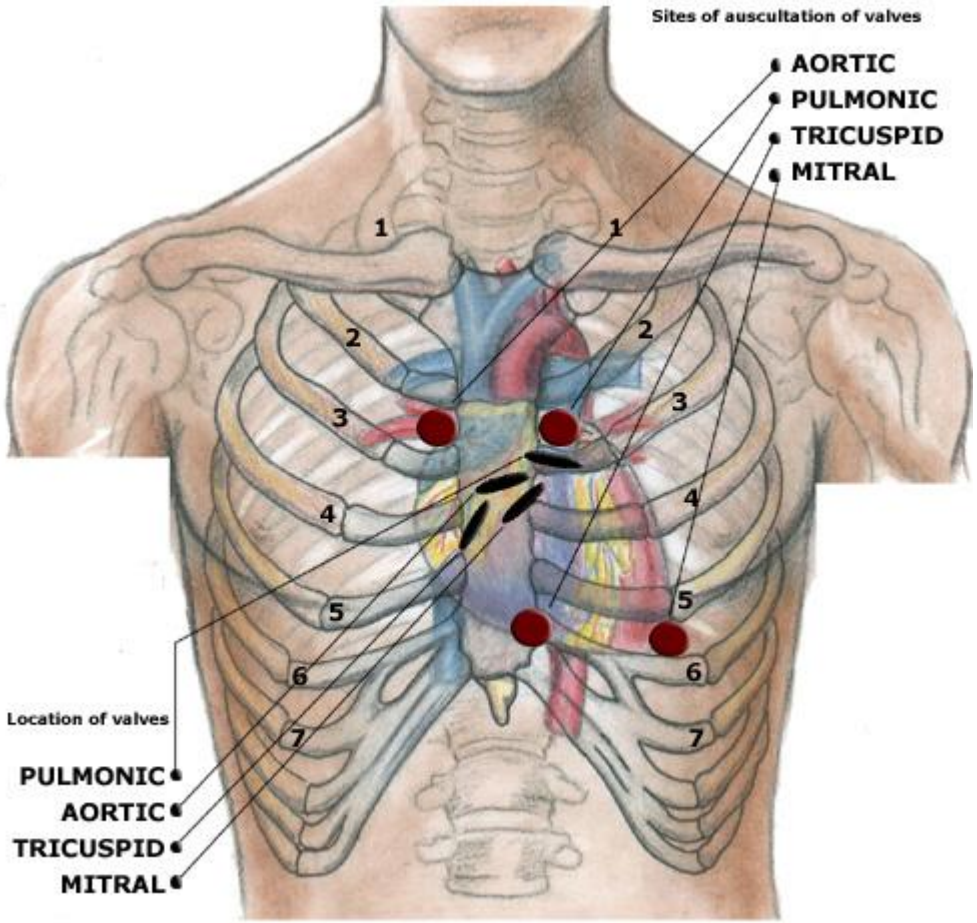
Surface projections of the heart



Surface projections of the heart valves

- The ***pulmonary valve*** projects at the sternal end of the left third costal cartilage.
- The ***aortic valve*** projects (just below and to the right of the pulmonary valve) behind of the left side of sternum at the level of the third intercostal space.
- The ***atrioventricular valves*** are projected on a oblique line passing over the sternum from the left third to the right fifth intercostal spaces.

Surface projections of the heart valves

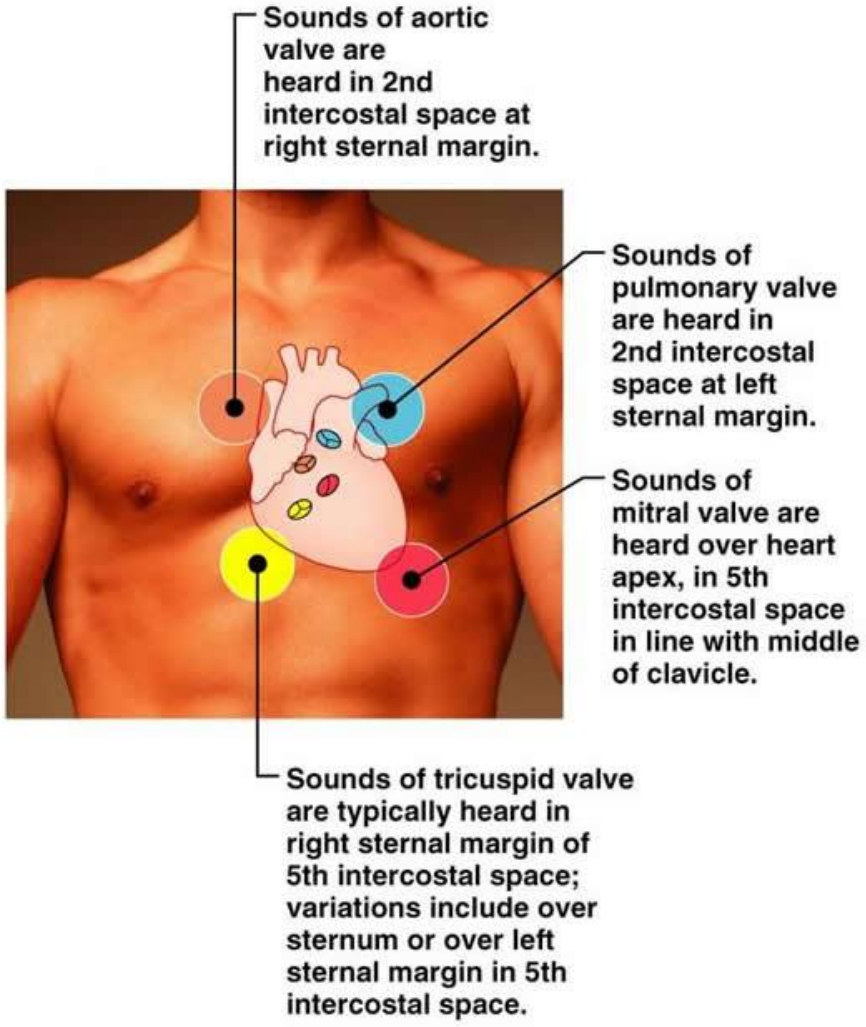


Auscultation of the heart

Auscultation points of valves:

- ***Aortic valve area*** – in the right second intercostal space, on the right sternal border;
- ***Pulmonary valve area*** – in the left second intercostal space, on the left sternal border;
- ***Erb`s point*** – in the left third intercostal space, on the left sternal border;
- ***Tricuspid valve area*** – on the base of the xiphoid process (variations include the fifth intercostal space over the left sternal border or over the right sternal border);
- ***Mitral valve area*** – in the left fifth intercostal space, on the left midclavicular line (1-1,5 cm medially).

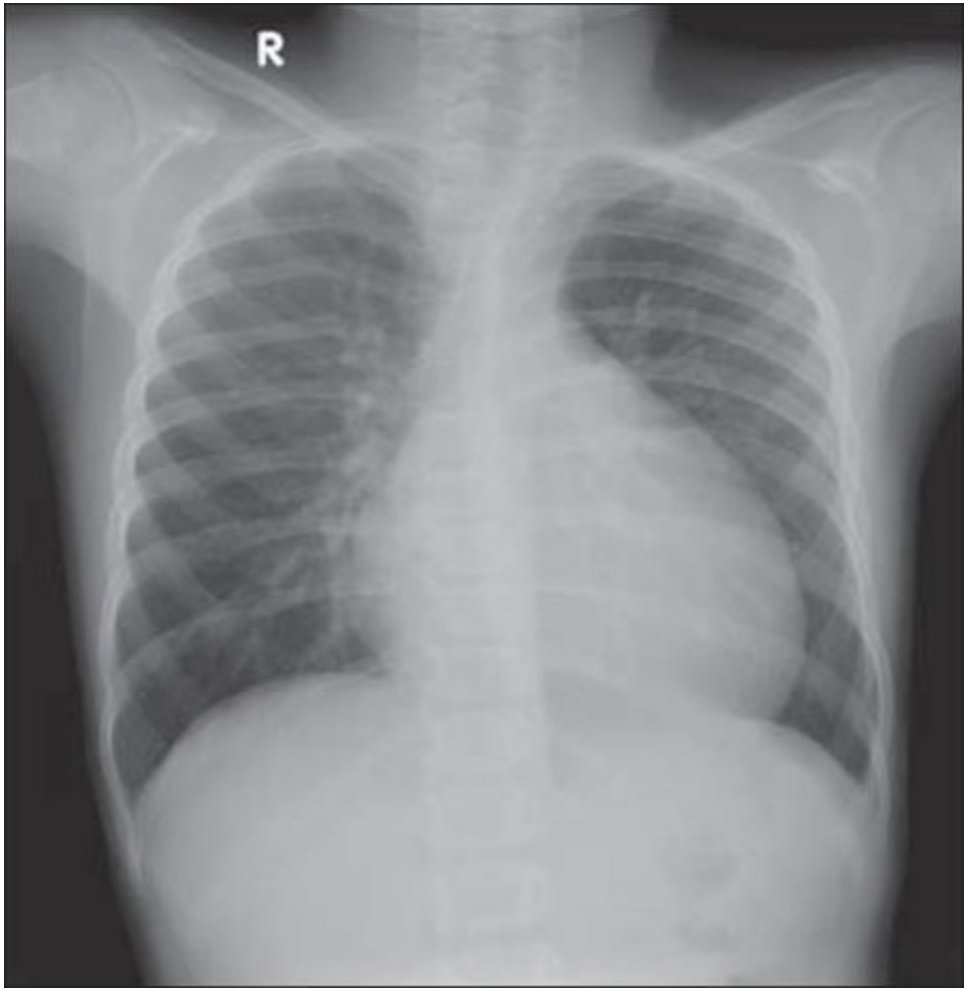
Auscultation of the heart



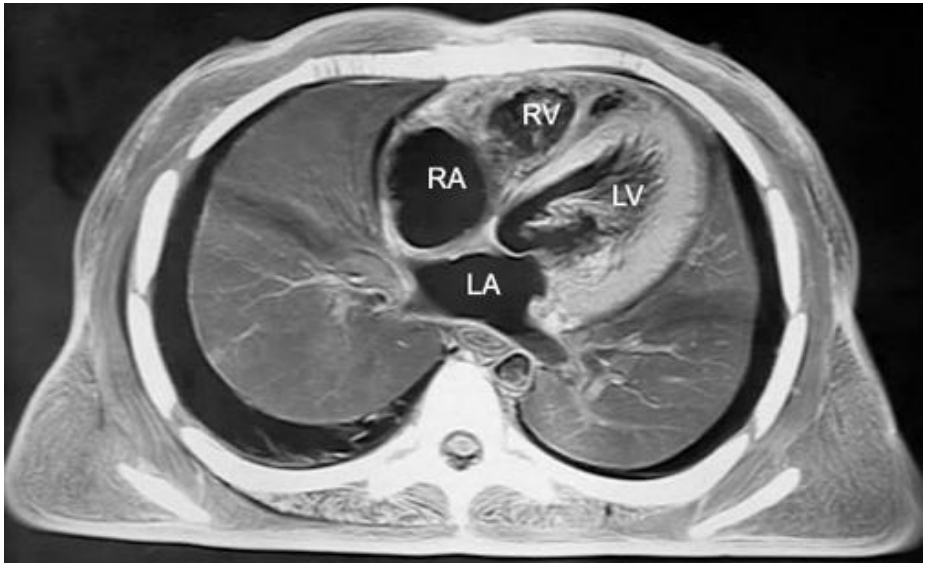
Paraclinical methods of examination

- ***X-ray examination;***
- ***Ultrasound examination;***
- ***CT (computed tomography);***
- ***Multidetector CT;***
- ***MRI (magnetic resonance imaging) or MRT (magnetic resonance tomography).***

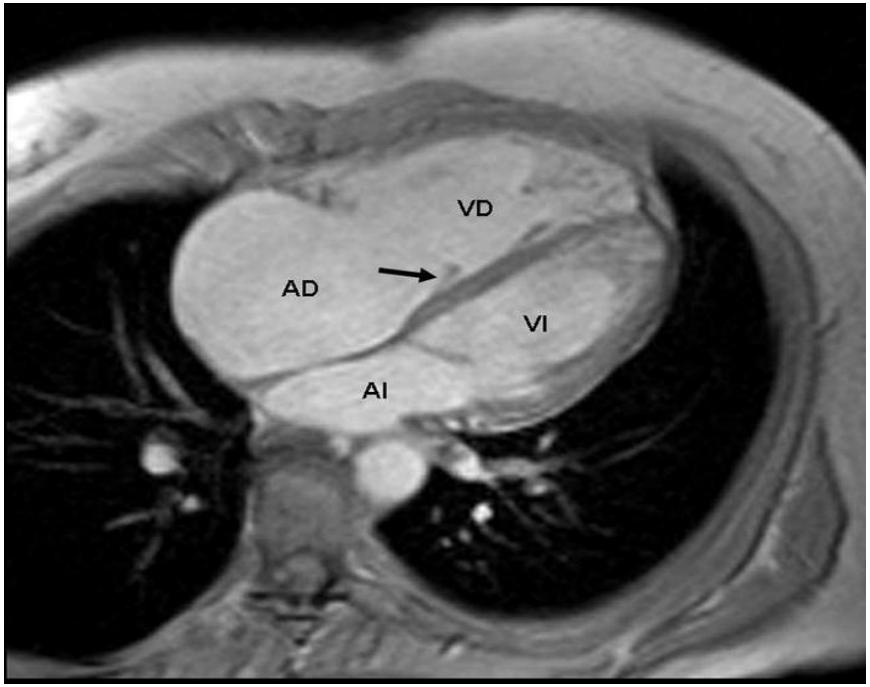
X-ray examination of the heart



CT (computed tomography)



MRI or MRT



Multidetector CT