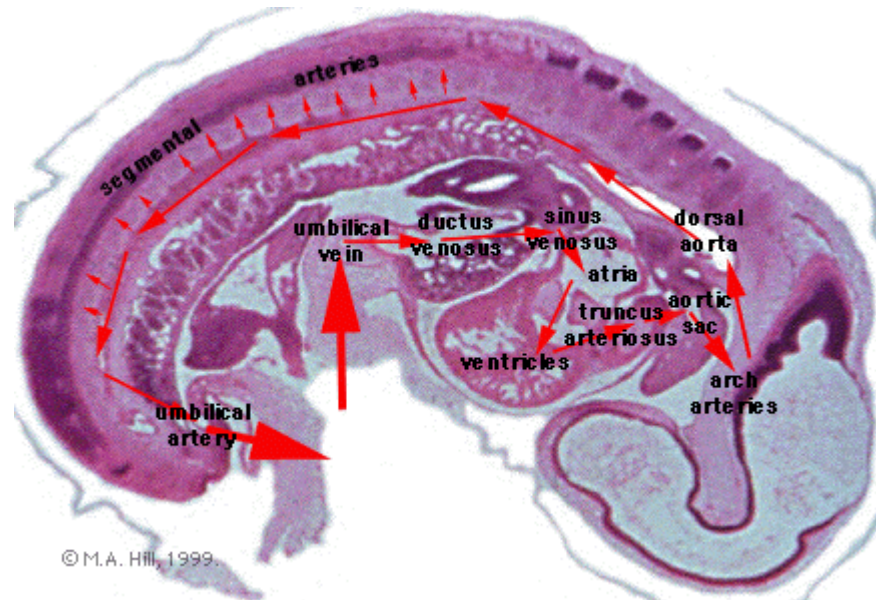
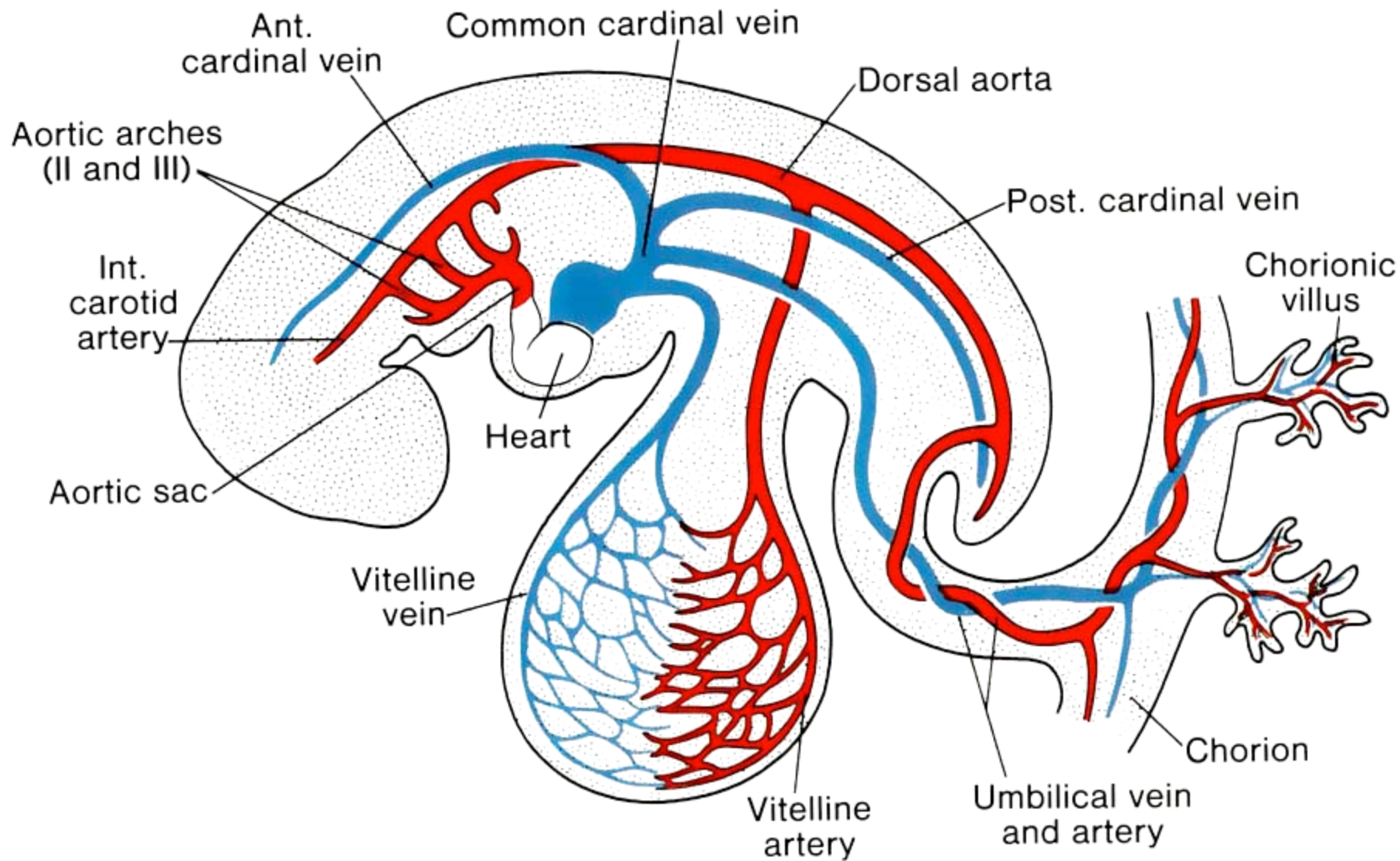
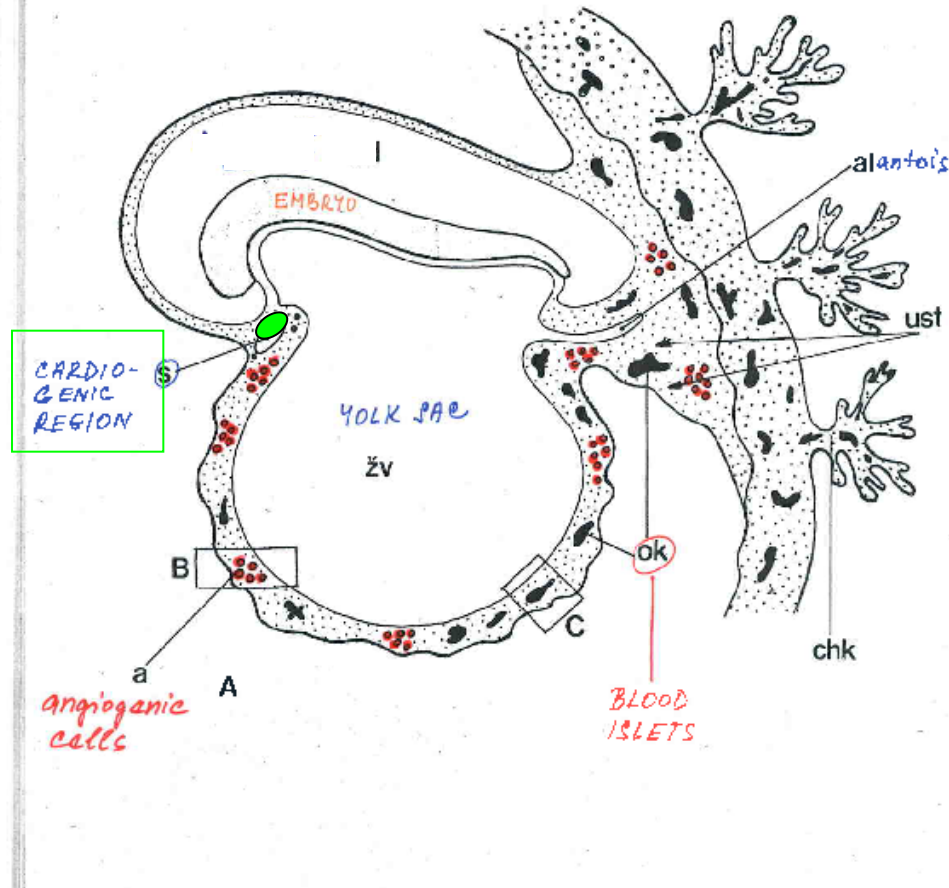


Development and teratology of cardiovascular and lymphatic systems



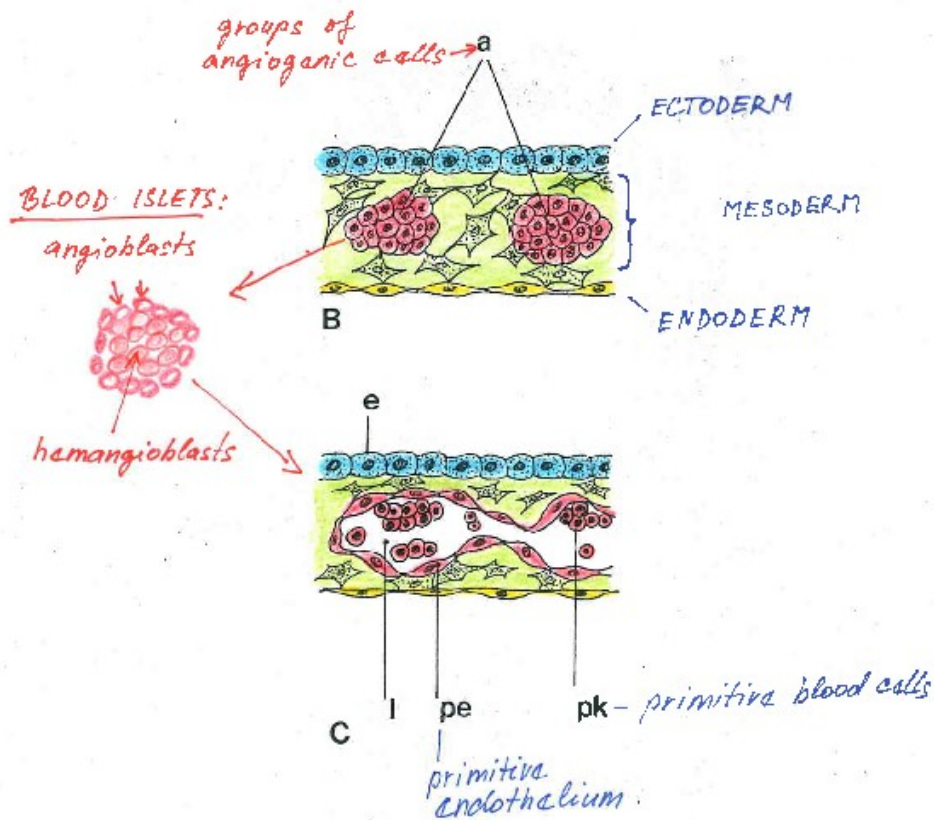
Repetition: Muscle tissue



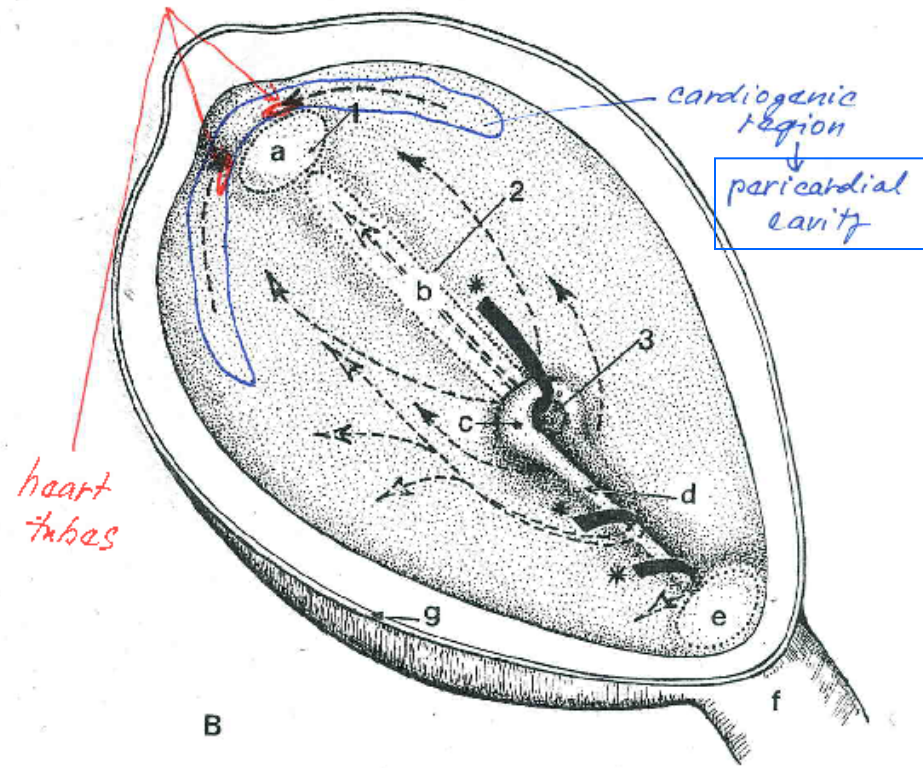


Beginning of the cardiovascular system development – the 3rd week:

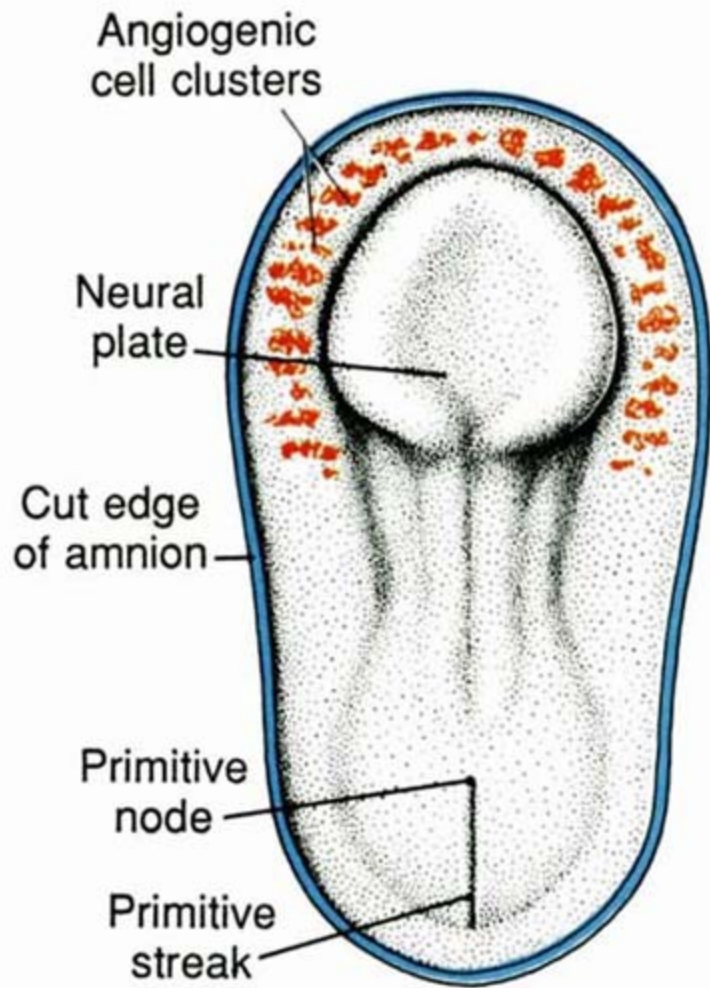
Hemangiogenesis (day 15 – 16) – **blood islets** (insulae sanguinae) in **extraembryonic mesoderm** and **splanchnic mesenchyme** of embryo



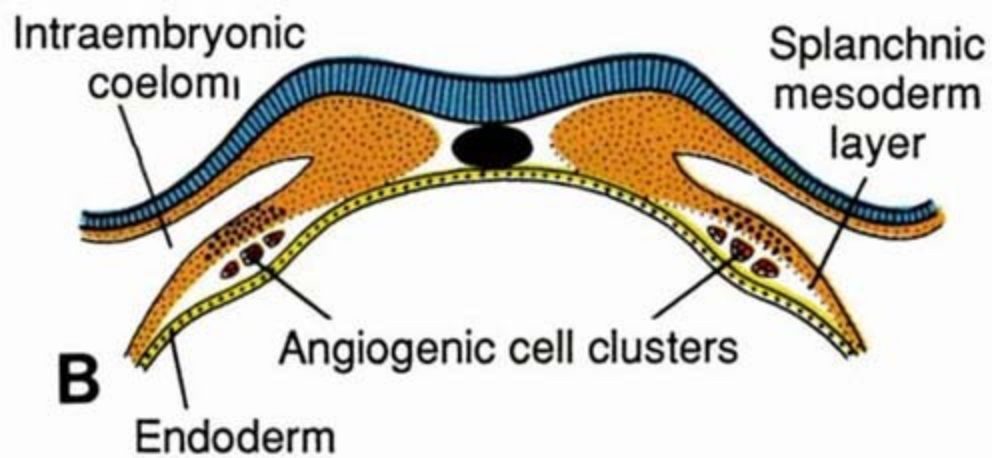
- Clusters of mesenchyme cells (angiogenic cells) differentiate into:
- **angioblasts** \Rightarrow **endothelium** (at the periphery of blood islets)
 - **hemoblasts** \Rightarrow **primitive erythrocytes** (in the center of blood islets)



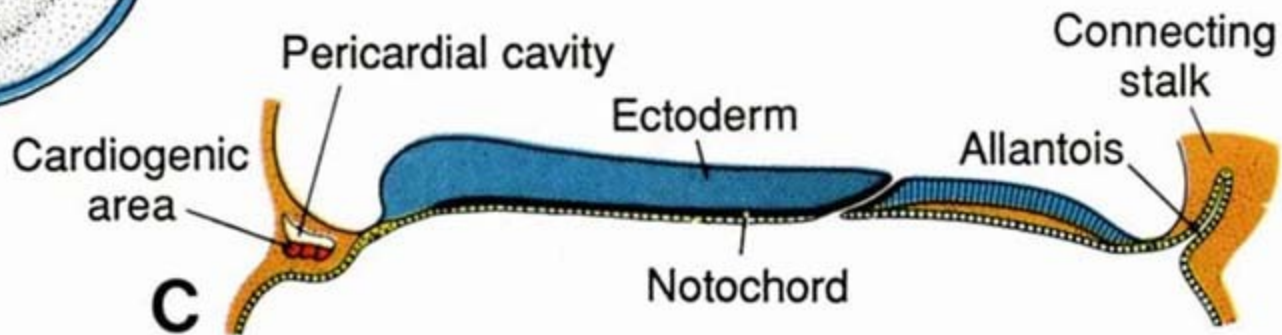
Clusters of **angiogenic cells** form a "horseshoe-shaped" space between somatic and splanchnic layer of mesoderm = **pericardial cavity**. Two endothelial tubes arise in splanchnic mesoderm. The ventral portion of these tubes forms the **cardiogenic area** with two **heart tubes**, while the lateral portions form the **dorsal aortae**.



A

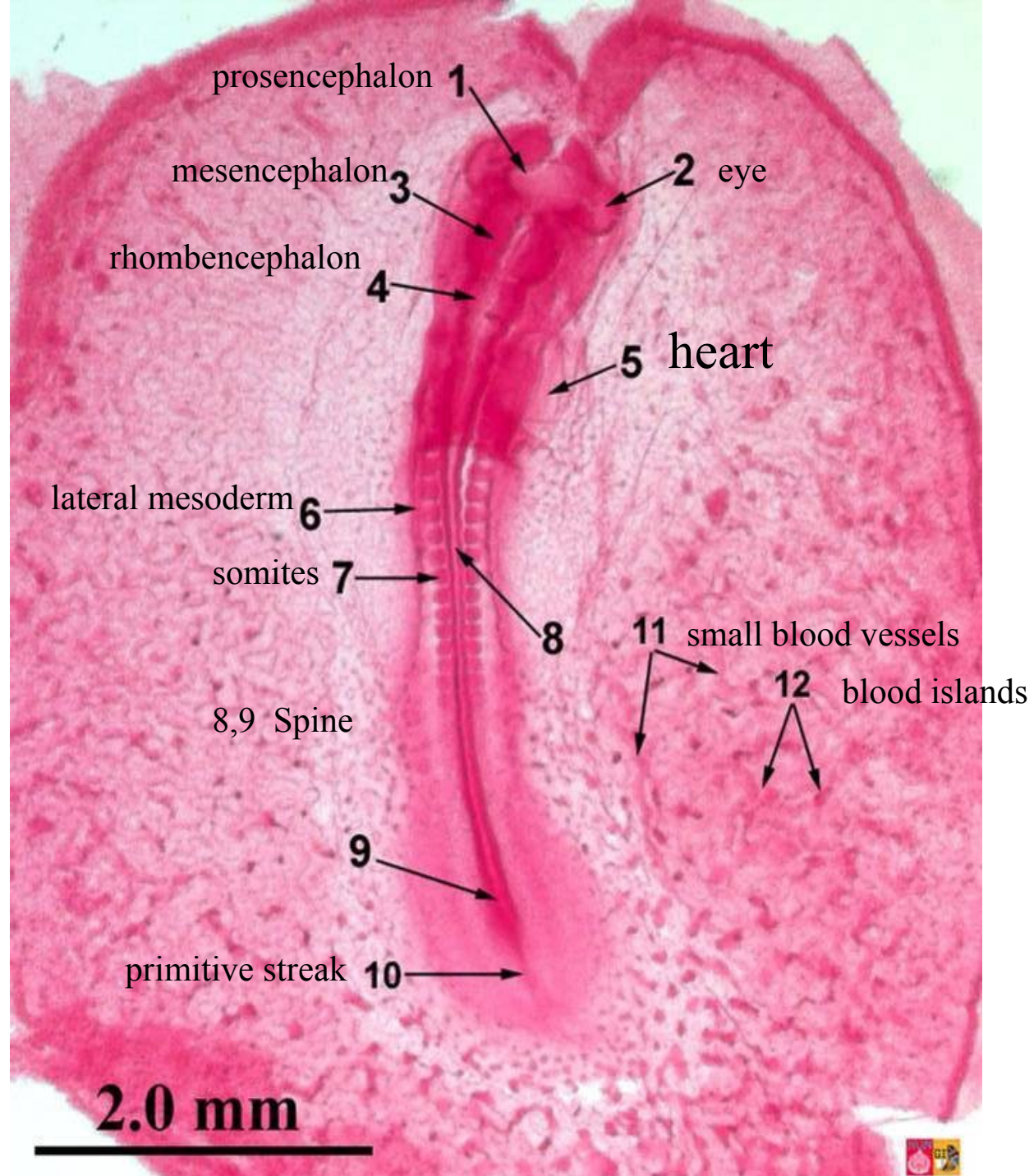


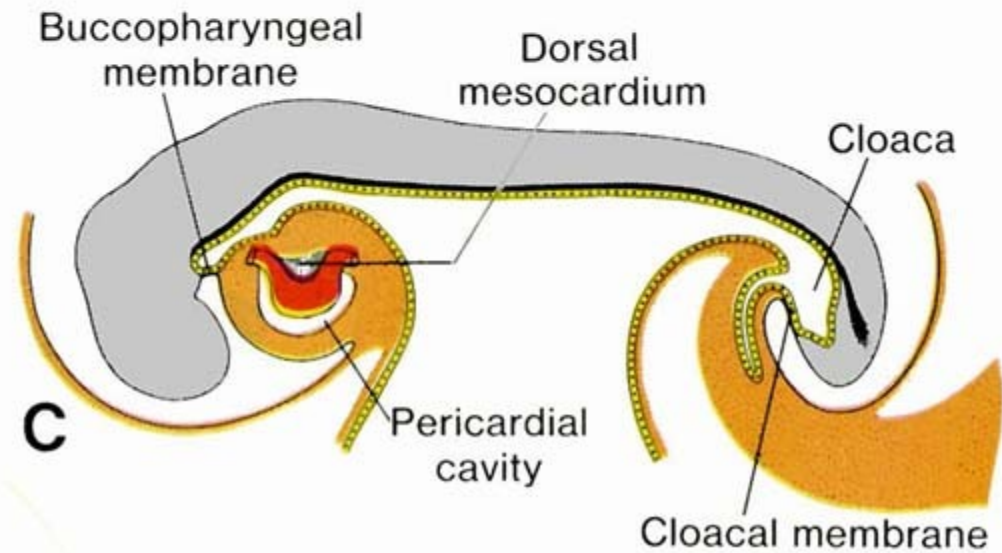
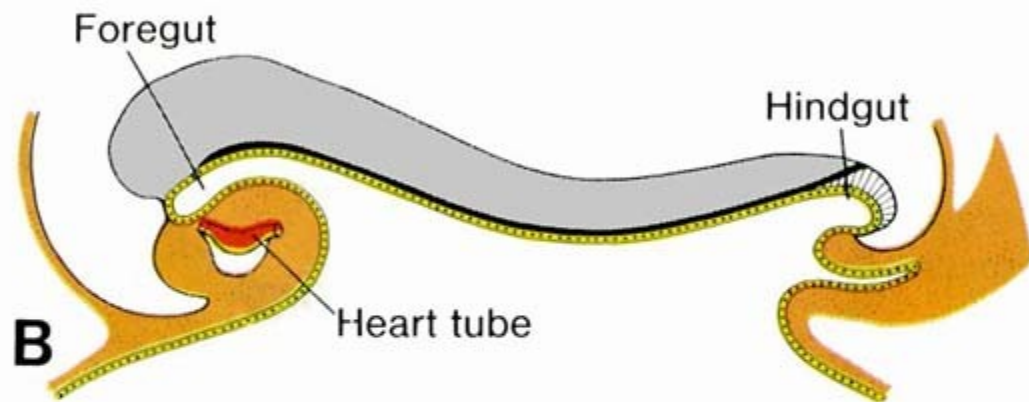
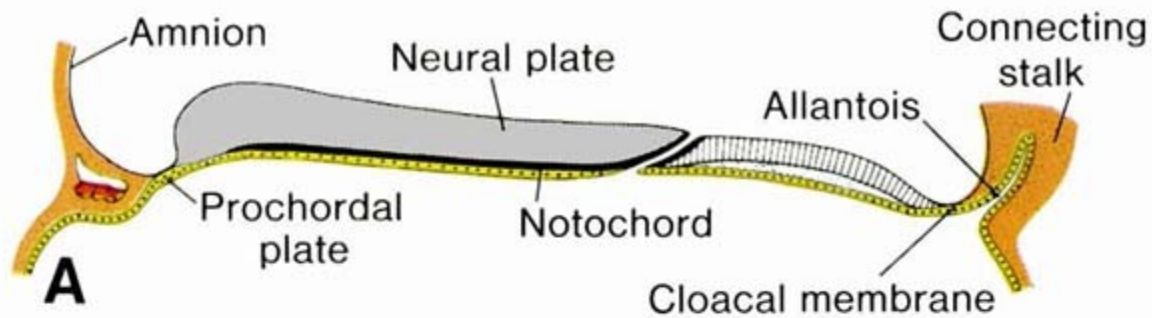
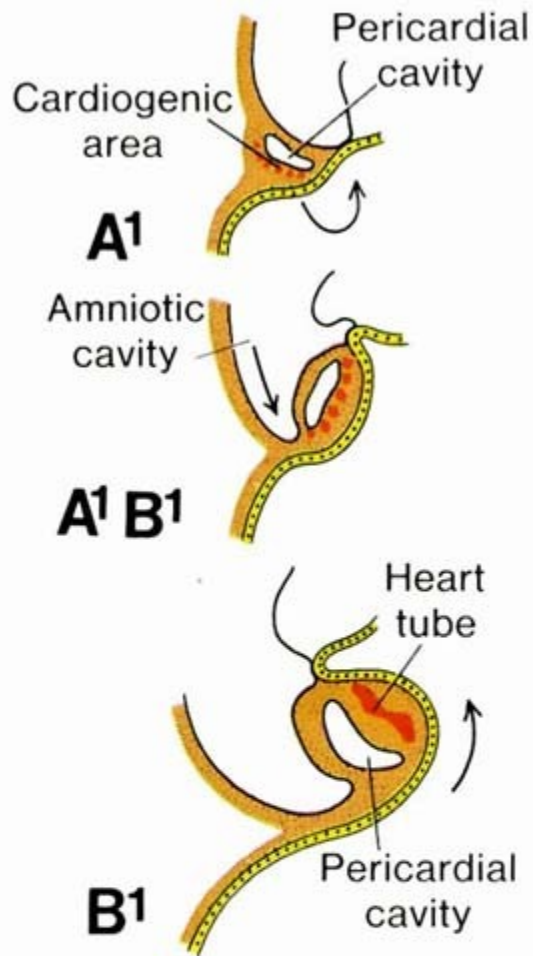
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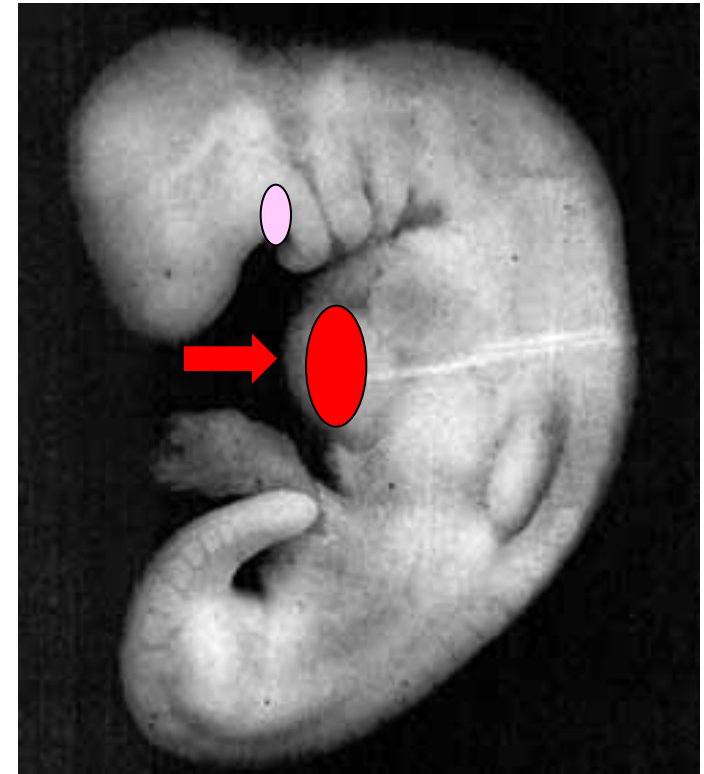
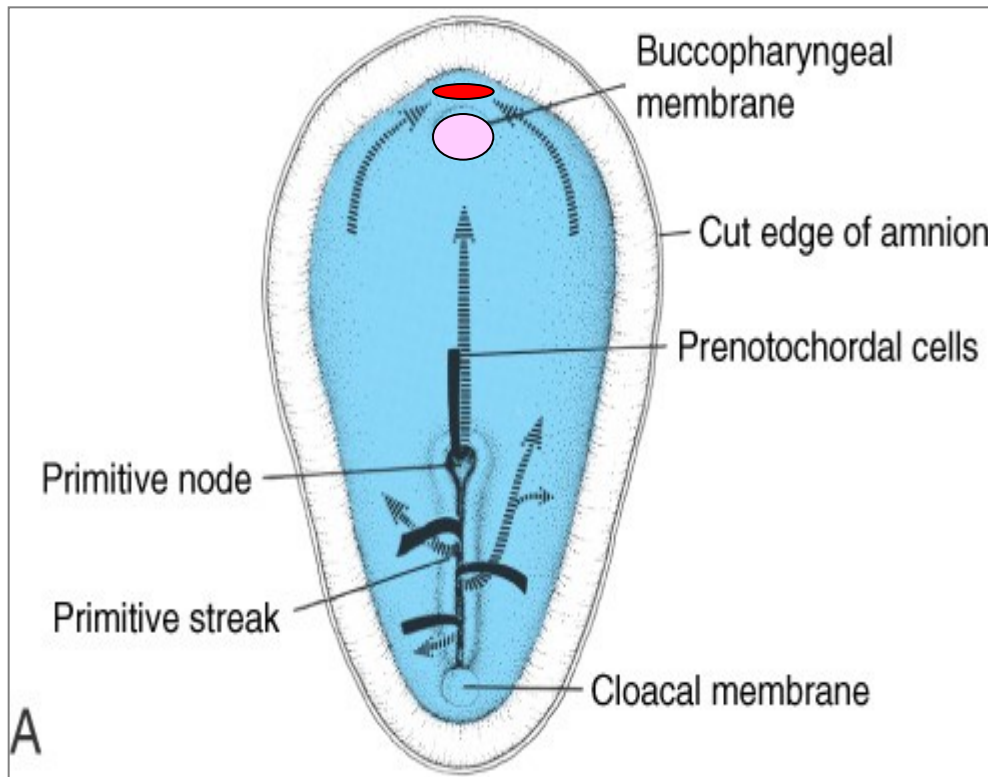
C

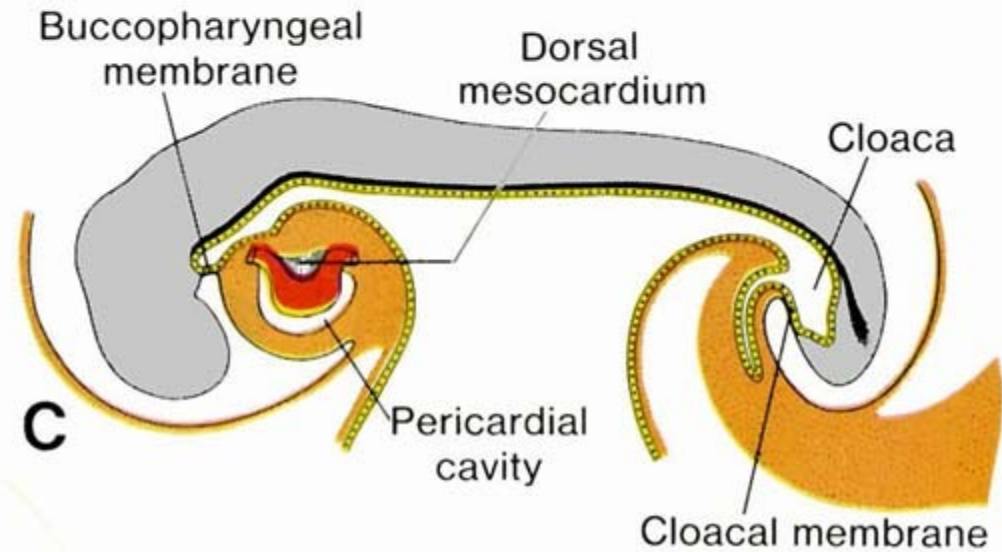
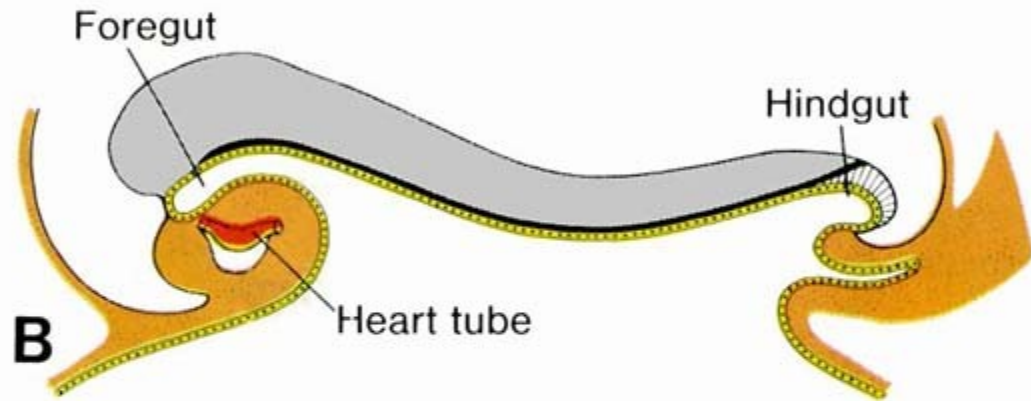
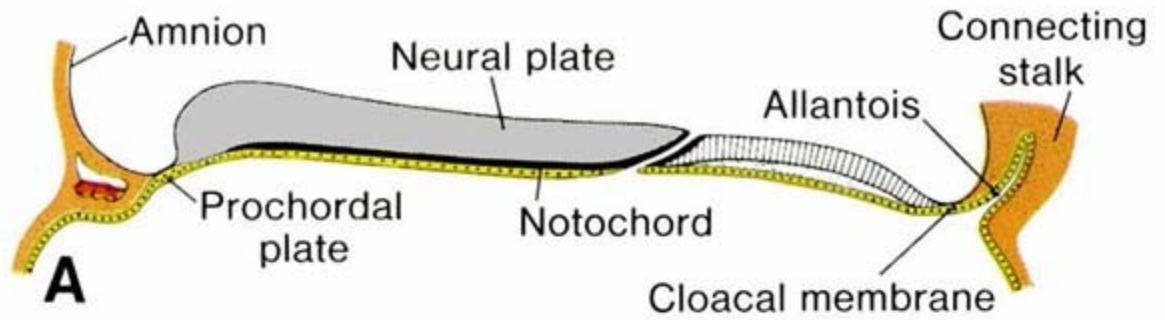
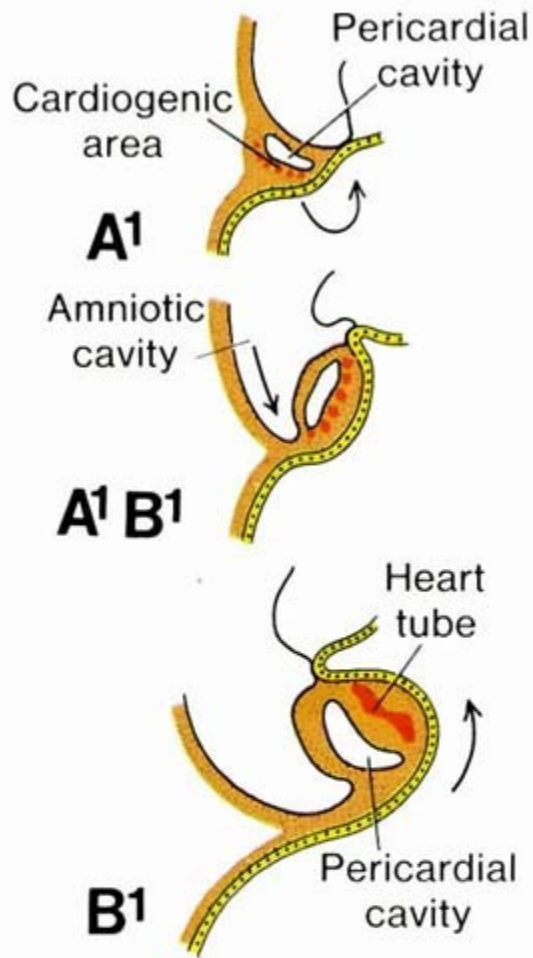
Germ disc:

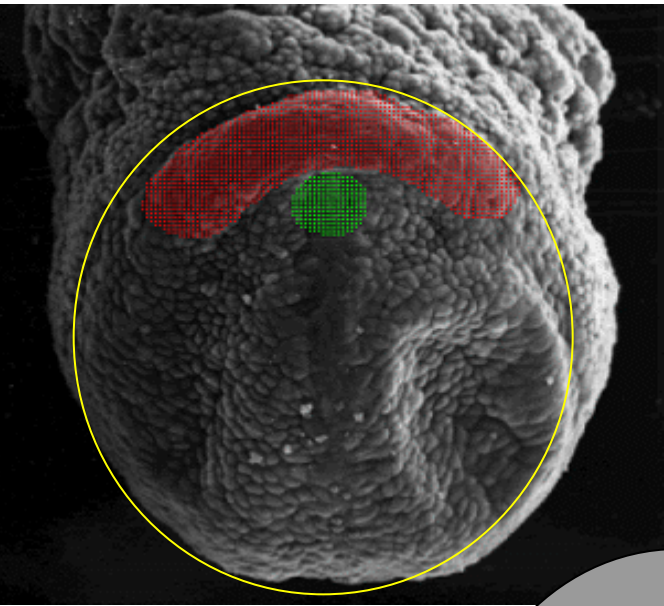




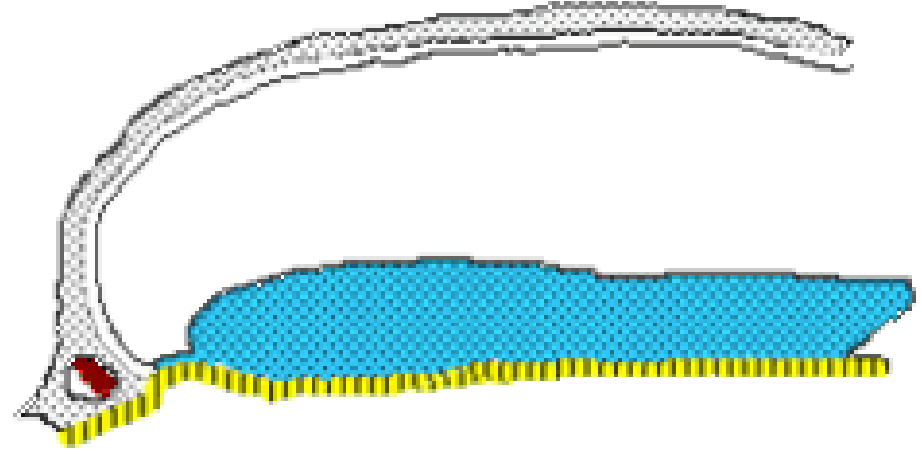
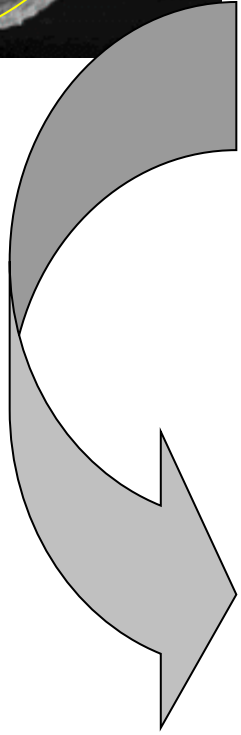
Initially, the cardiogenic area is located anterior to the prechordal plate and the neural plate. The growth of the central nervous system pulls the cardiogenic area and prechordal plate (buccopharyngeal membrane ventrally and caudally (→)).

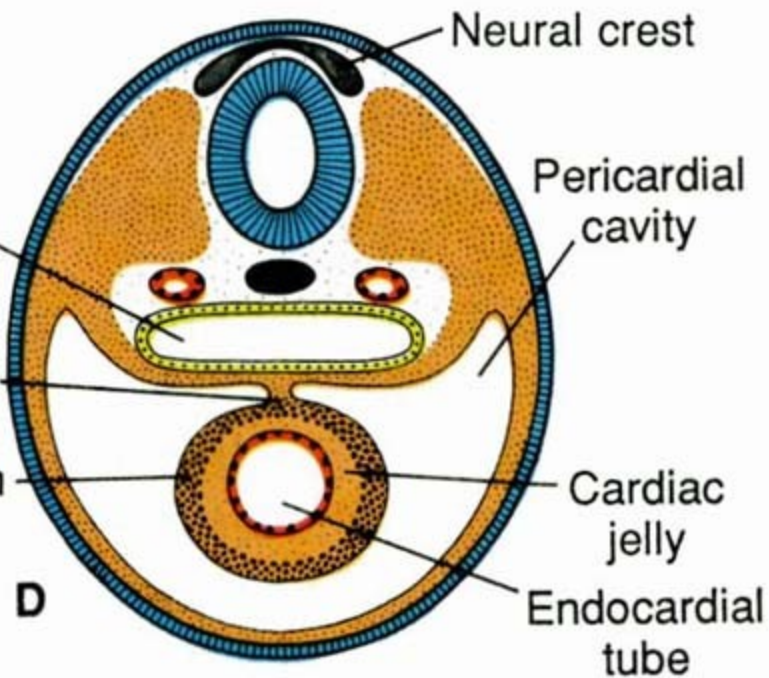
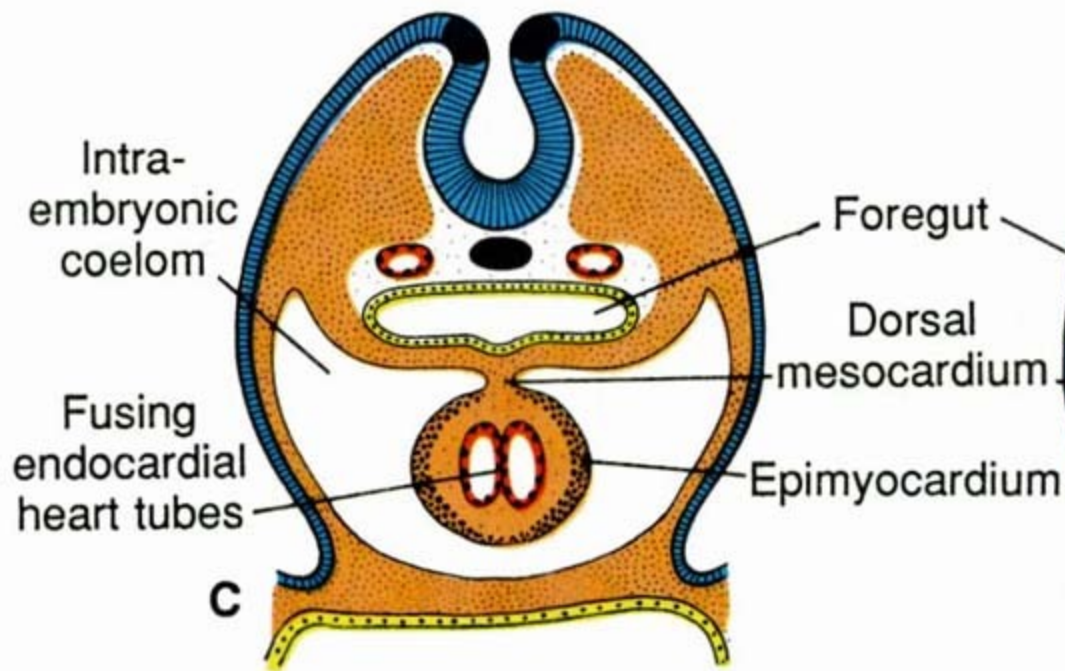
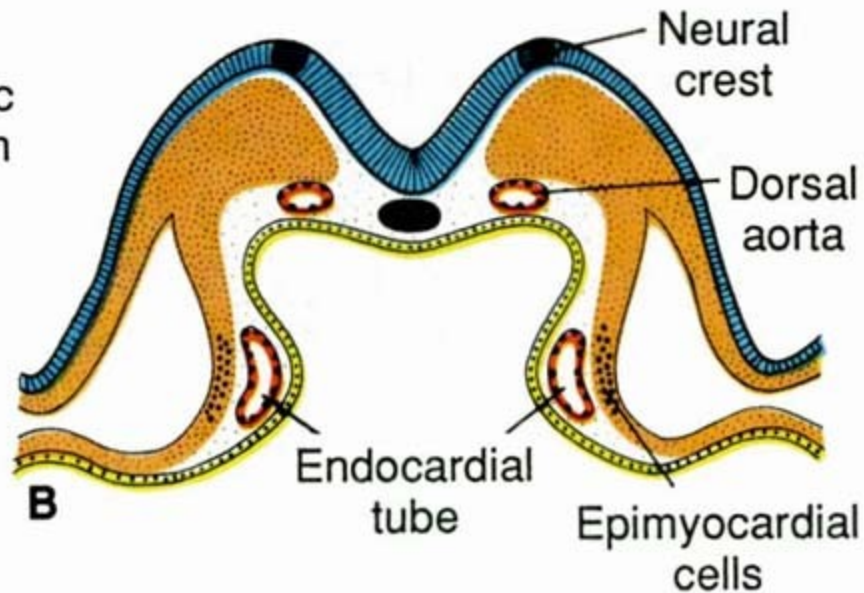
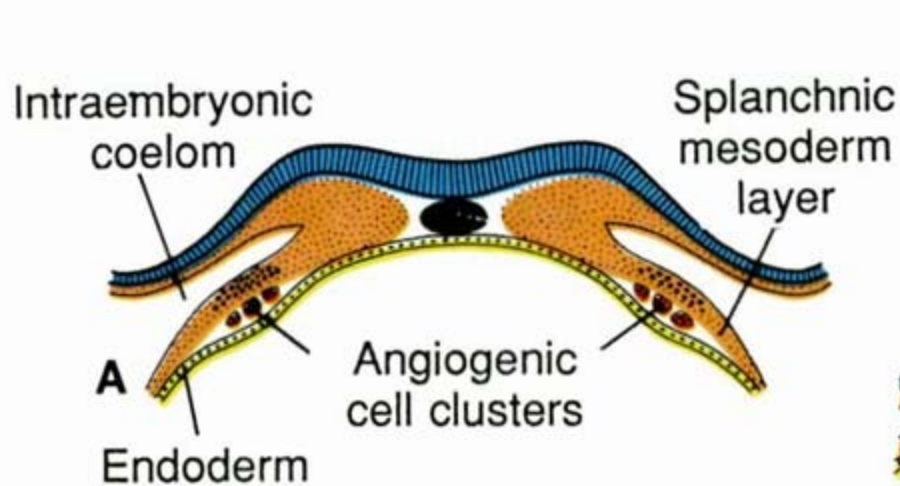




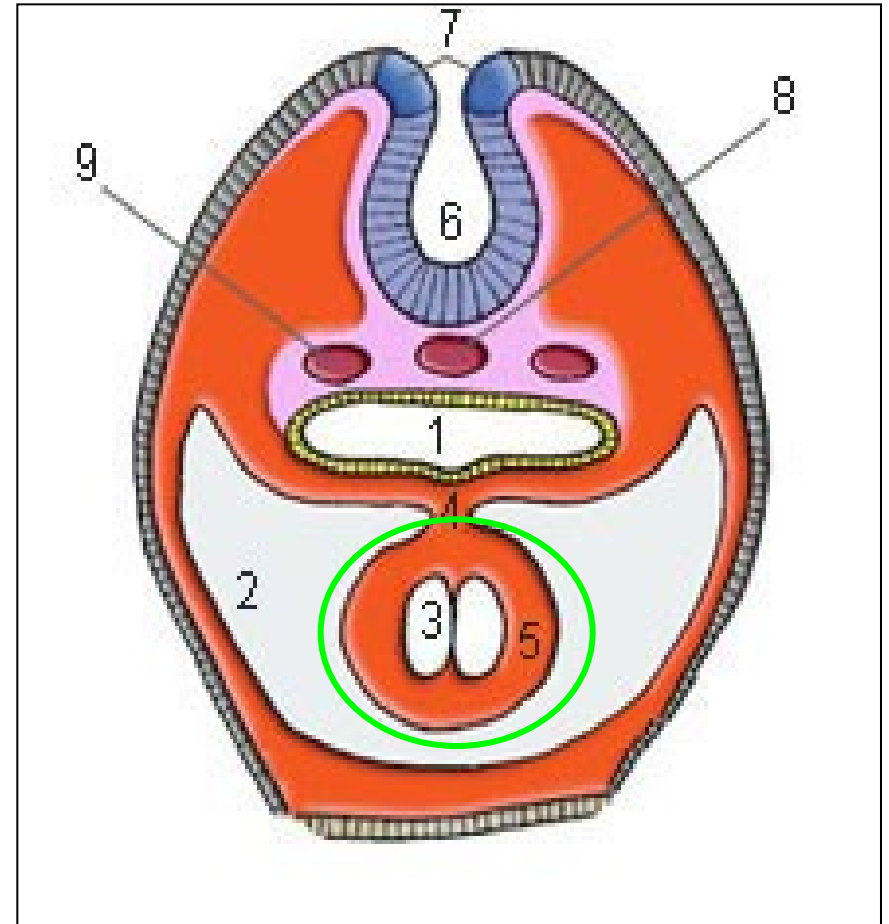
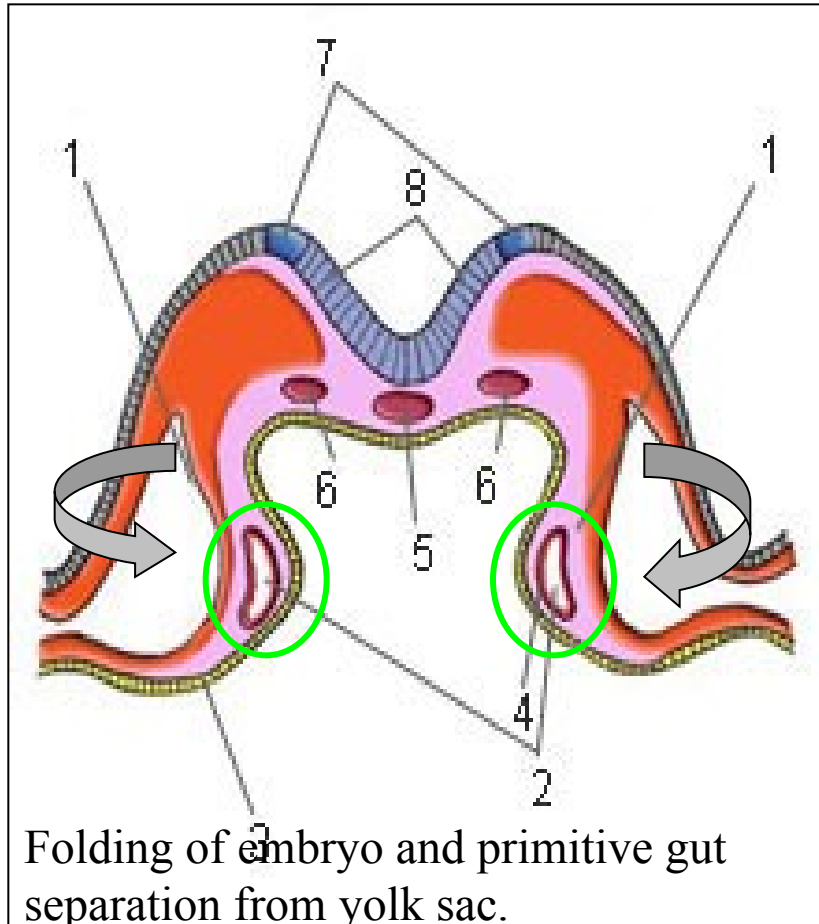


Cardiogenic region just cranial to the prechordal plate.



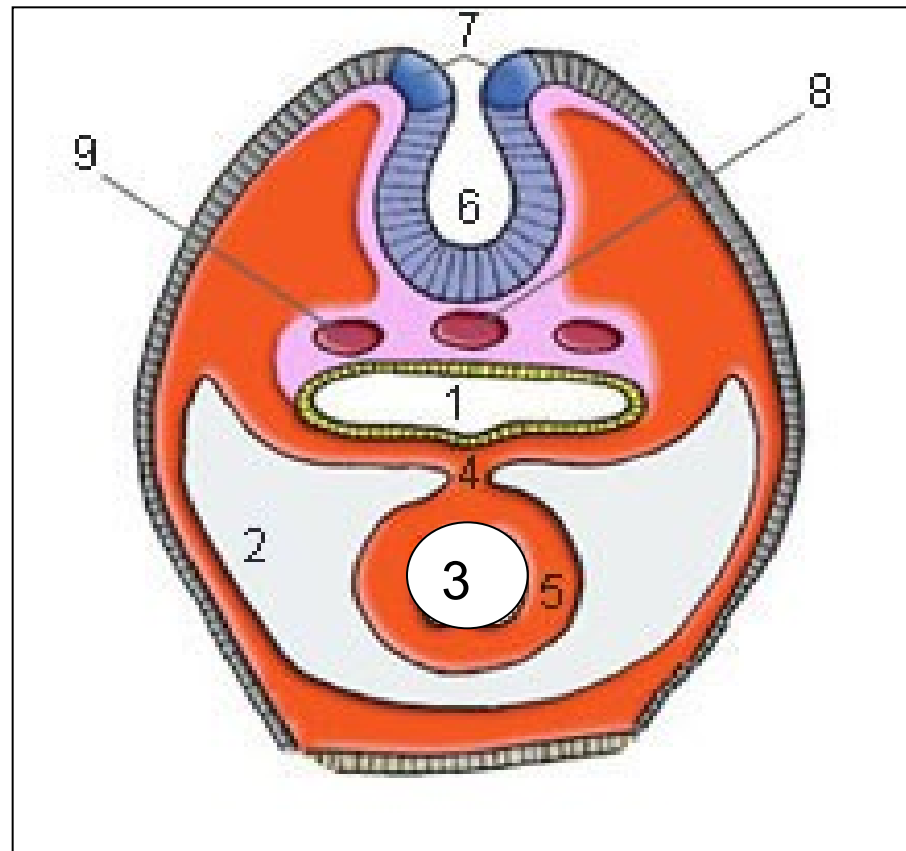


The canalization of cardiogenic clusters in the splanchnic mesoderm results in the formation of the paired heart tubes.



Fusion of the heart tubes

a single heart tube is, temporarily attached to the dorsal side of the pericardial cavity by the **dorsal mesocardium** (4). The splanchnic mesoderm (5) around the heart tube (3 - future **endocardium**) thickens and forms the heart jelly = myoepicardial mantle (future **myocardium** and **epicardium**).



Heart tube

Truncus arteriosus + aortic roots

Bulbus cordis

Ventricle

Atrium

Sinus venosus

Common cardinal veins

Umbilical veins

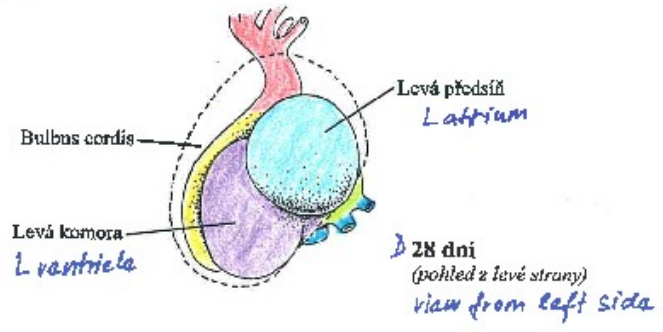
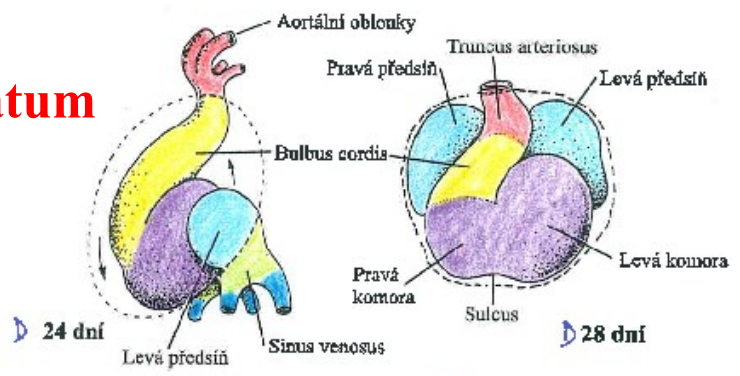
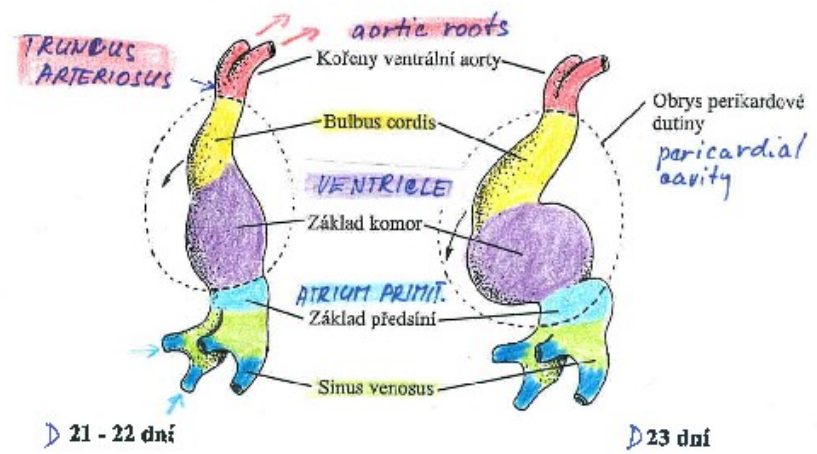
Vitelline veins

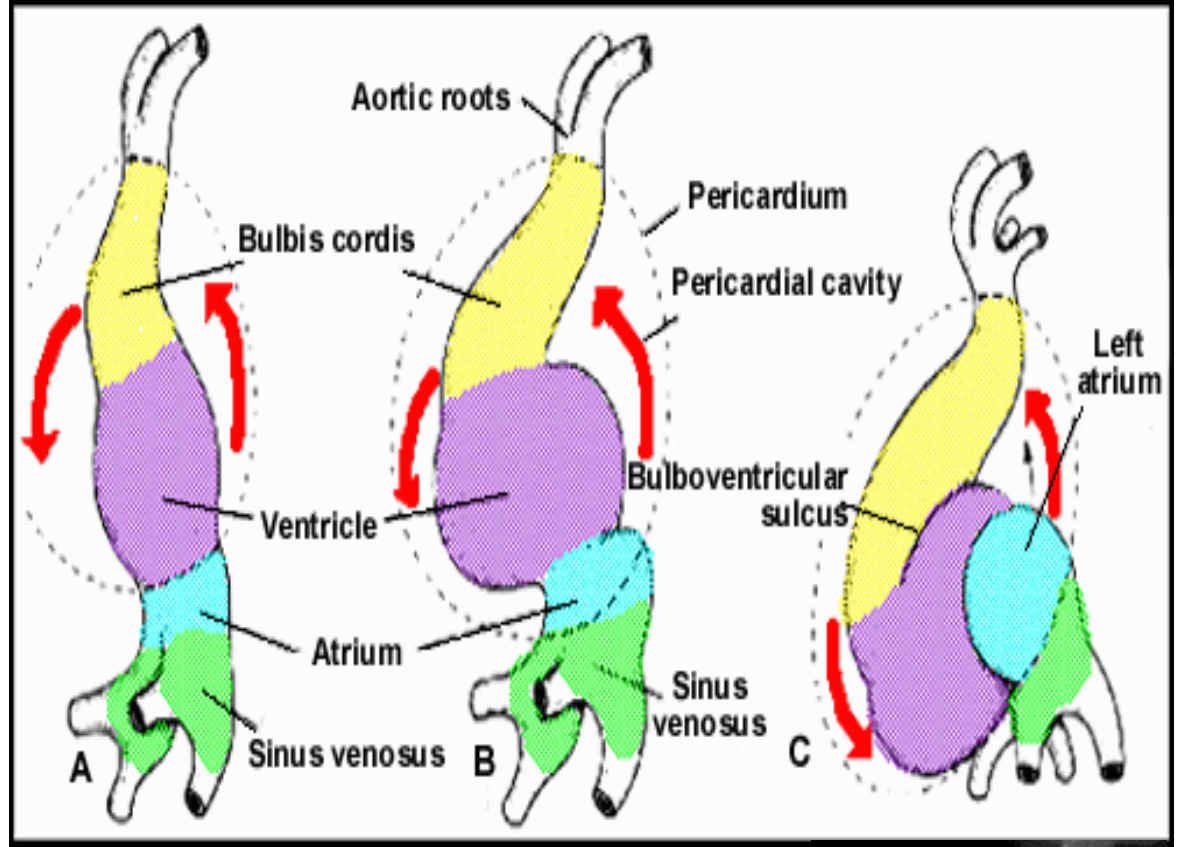
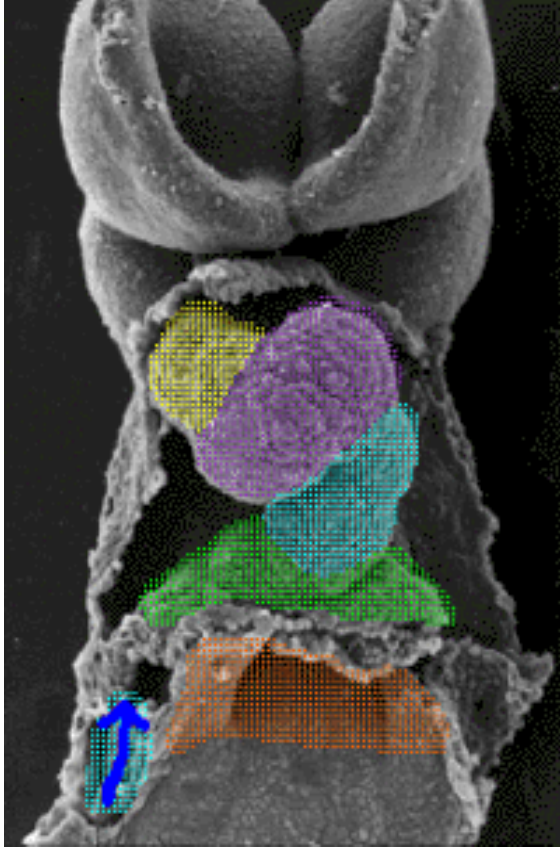


Cor tubulare

Cor sigmoideum

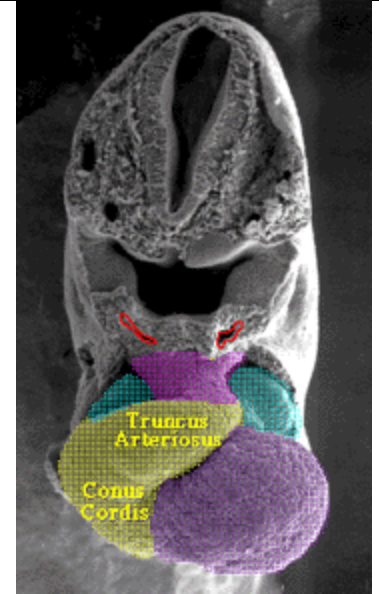
Cor quadricameratum





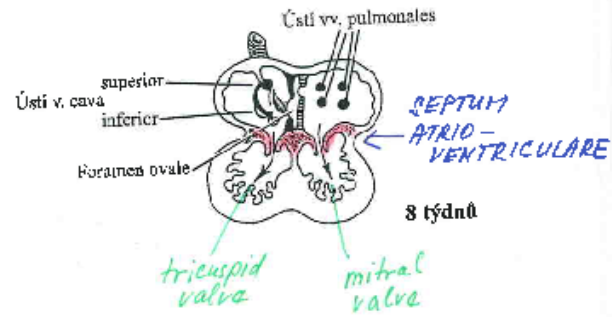
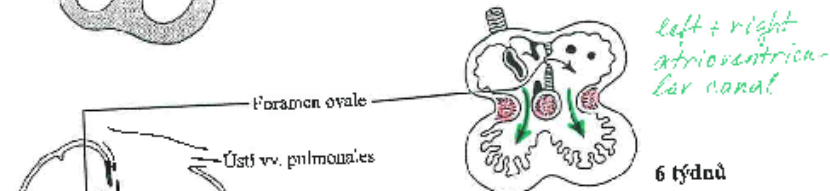
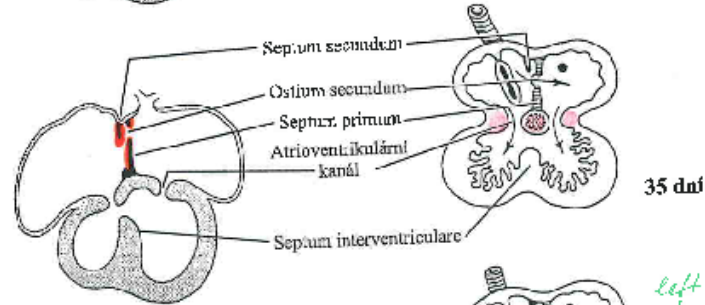
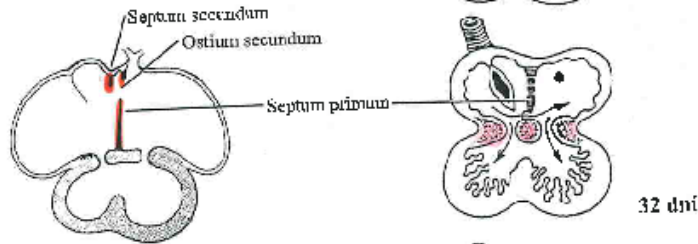
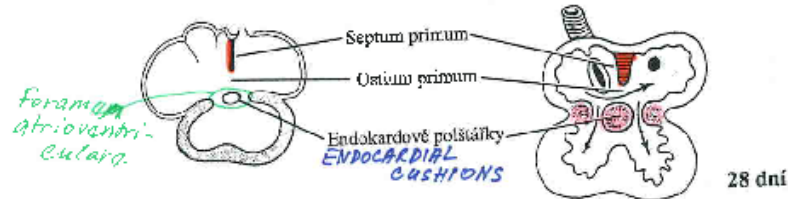
Looping of the heart tube

- because growth of the heart tube is faster than growth of the pericardial cavity



Cor quadricameratum

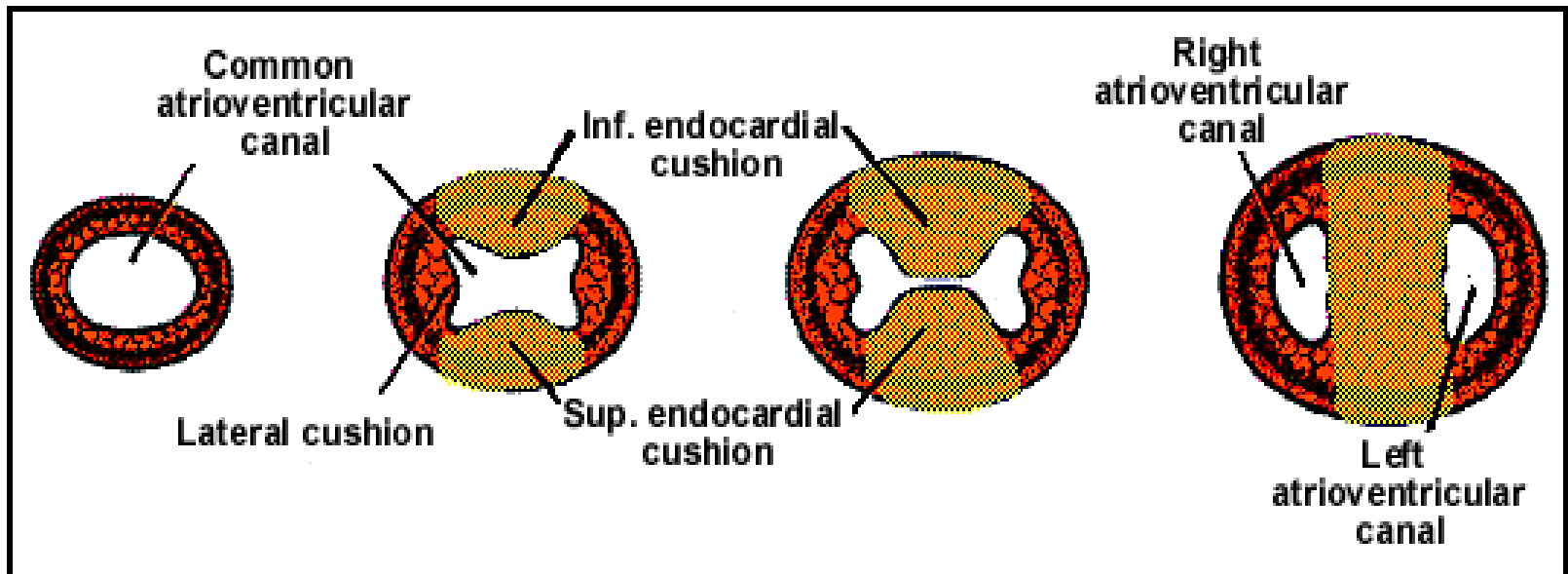
SEPTUM ATRIORUM

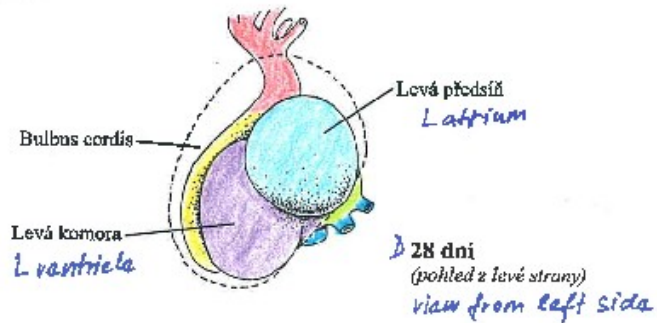
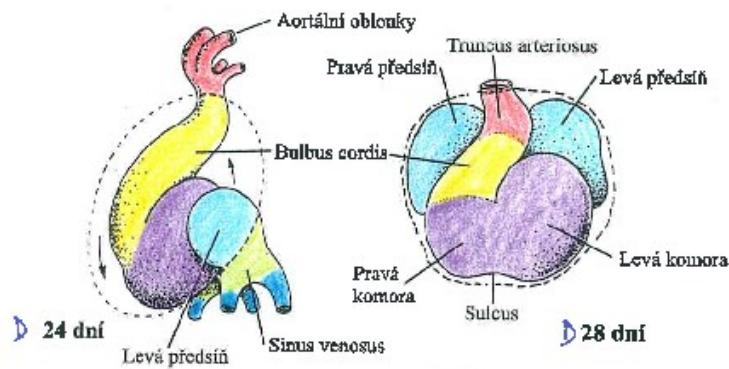
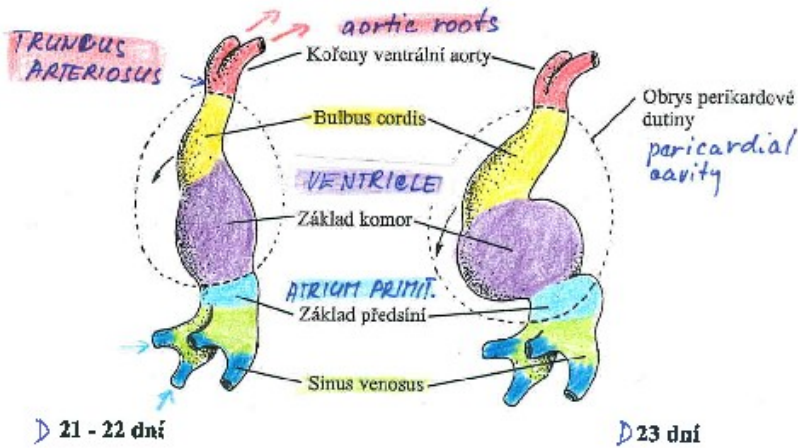


Atrioventricular septum

Endocardial cushions develop in the dorsal and ventral walls of the heart in the region of the atrioventricular canal. They grow towards each other and fuse, thus **dividing the atrioventricular canal** into right and left orifices.

The lateral interventricular cushions appear on the sides of the canal. These proliferations of the mesenchymal tissue subsequently differentiate into **bicuspid** and **tricuspid atrioventricular valves**.

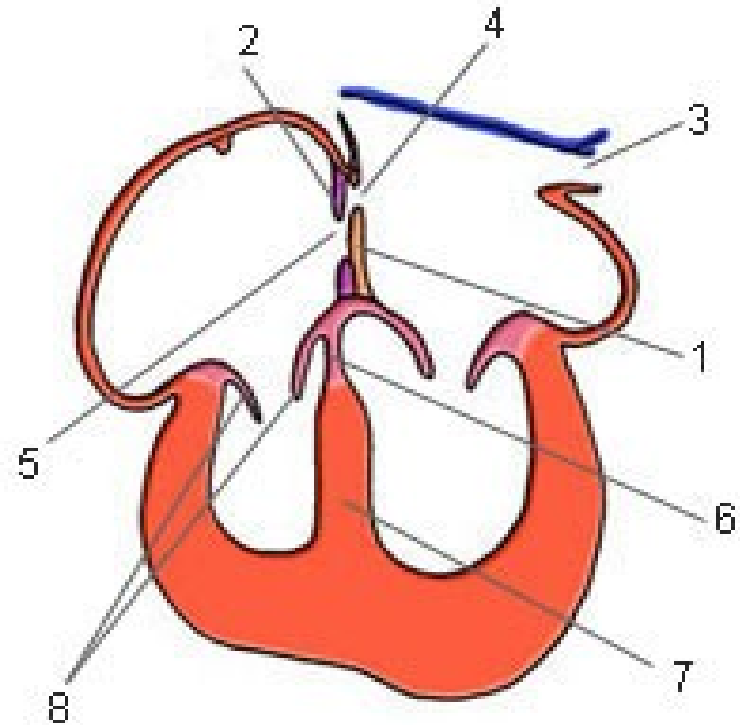




Ventricle

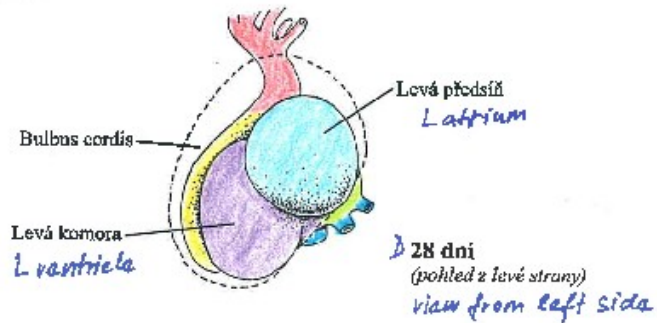
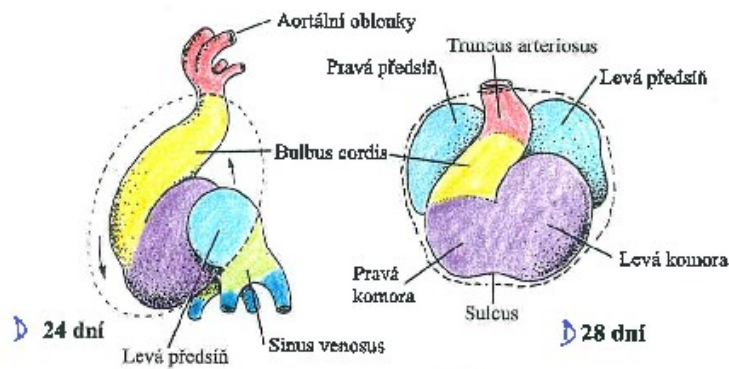
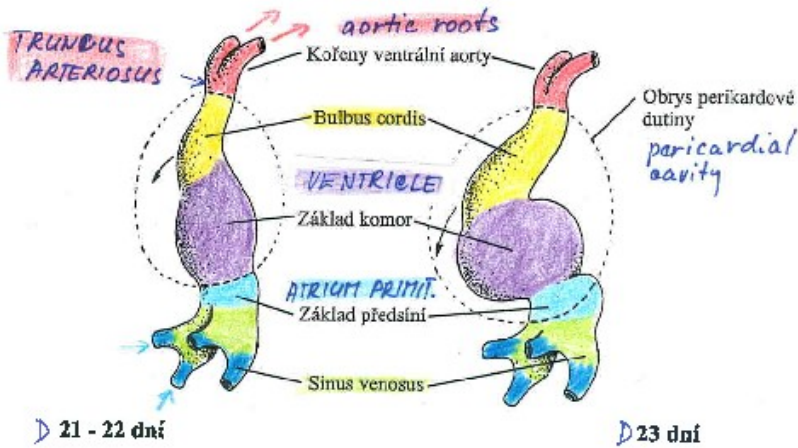
Septum interventriculare

Grows from the heart apex cranily to the endocardial cushions (AV septum)



6 - membranaceous part of septum

7 - IV septum

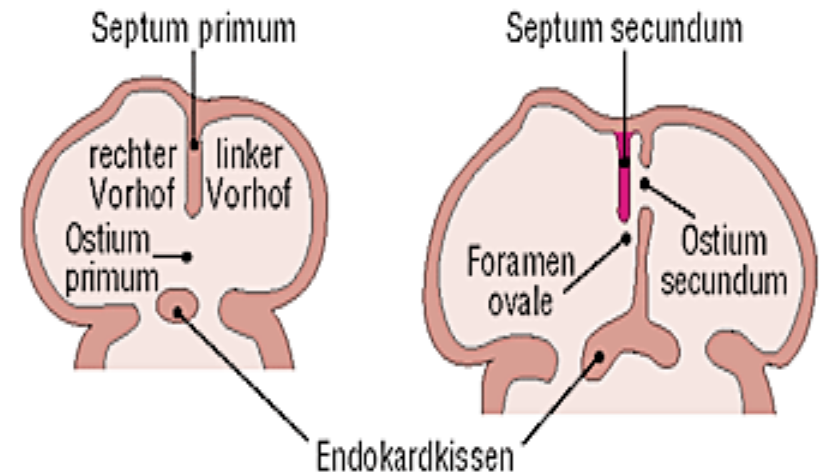


Atrium

Septum atriorum

-septum primum with ostium primum (obliterates); ostium secundum

-septum secundum with foramen ovale

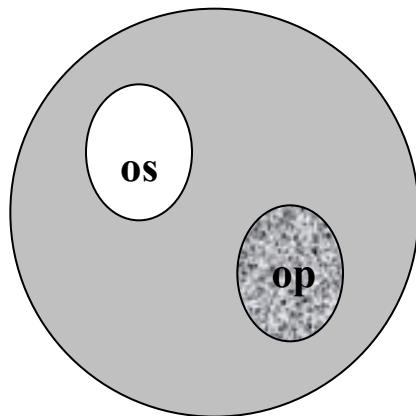


Atrium

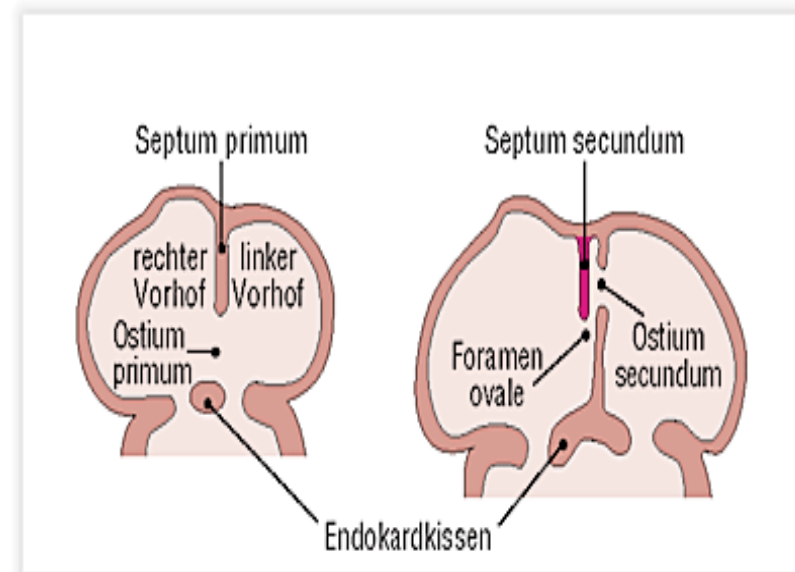
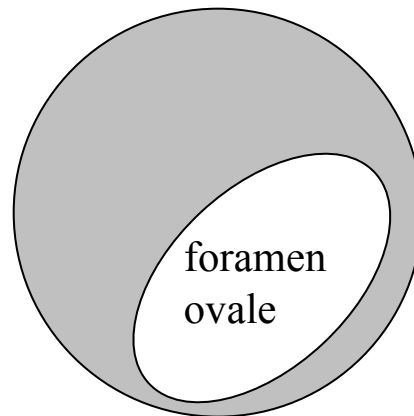
At the end of the 4th week, **septum primum** grows from the dorsocranial wall of the primitive atrium towards the endocardial cushions. The temporary opening (**ostium primum - op**) between the lower rim of the septum primum and the endocardial cushions gradually closes. Perforations in the upper part of the septum primum form the **ostium secundum - os**.

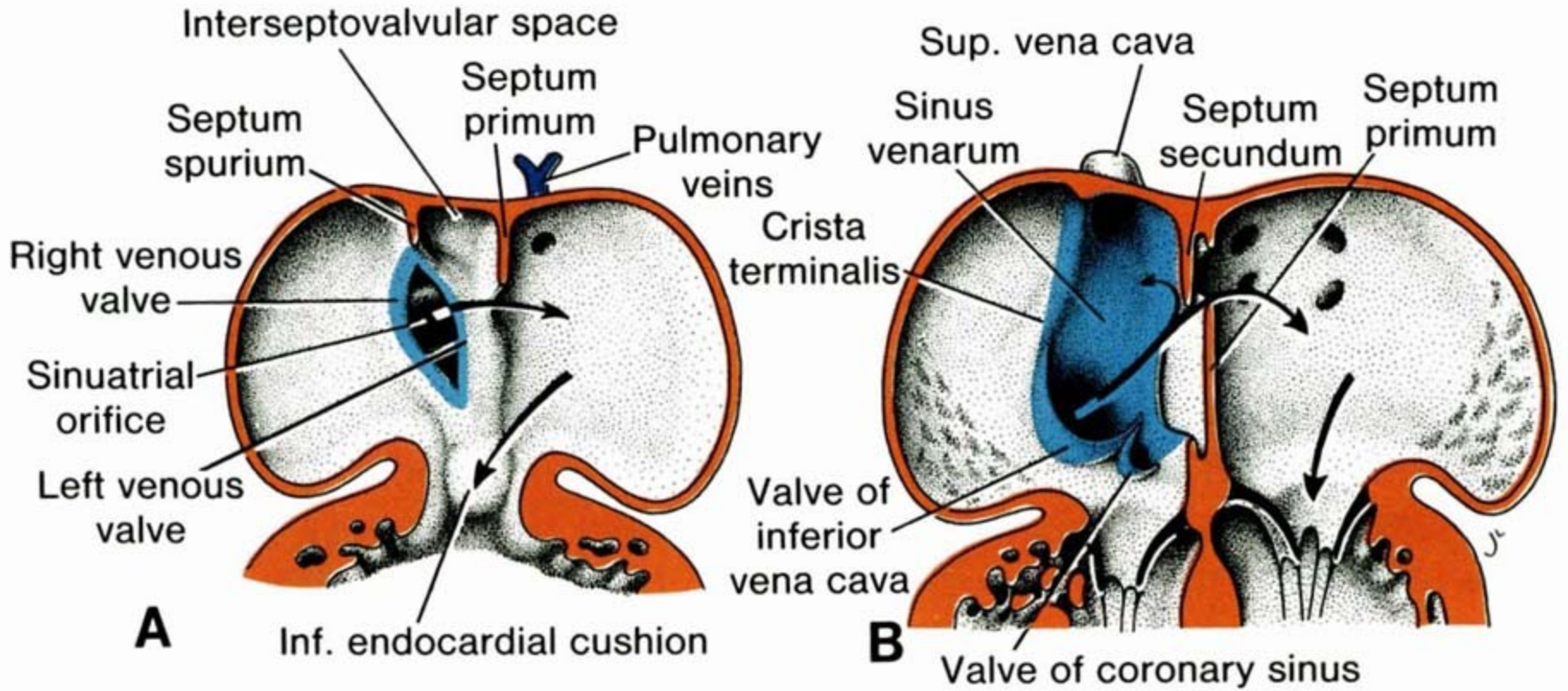
Subsequently, another crest (**septum secundum**) grows from the right side of the septum primum and gradually covers the foramen secundum. The oval opening left by the septum secundum is called **foramen ovale**.

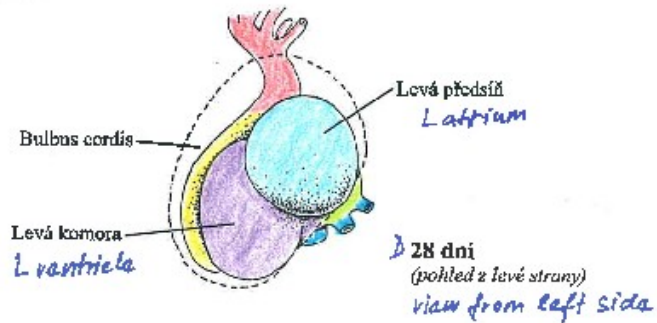
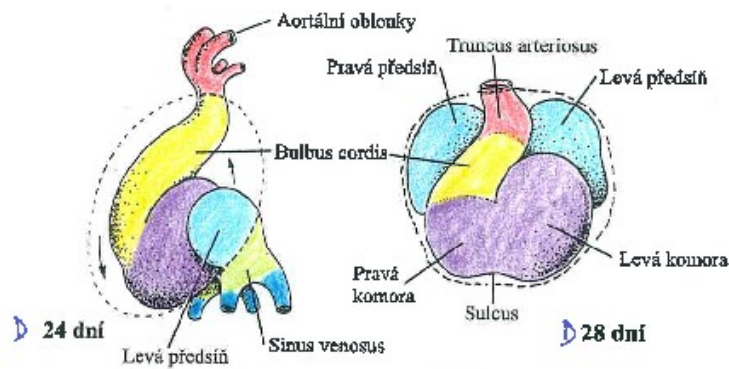
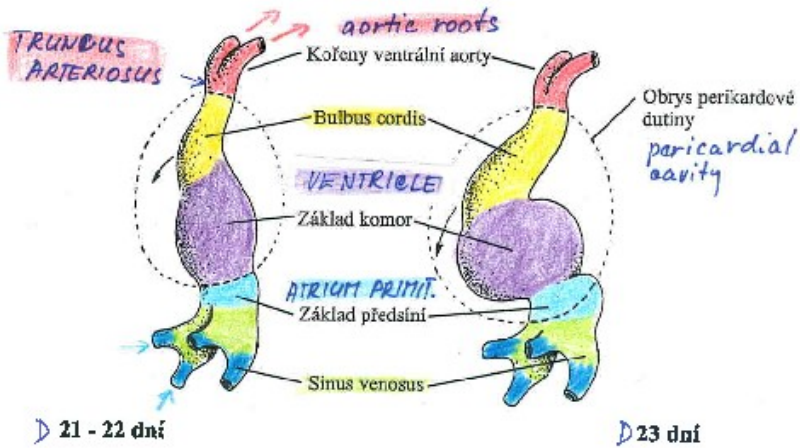
Septum primum



Septum secundum







Sinus venosus

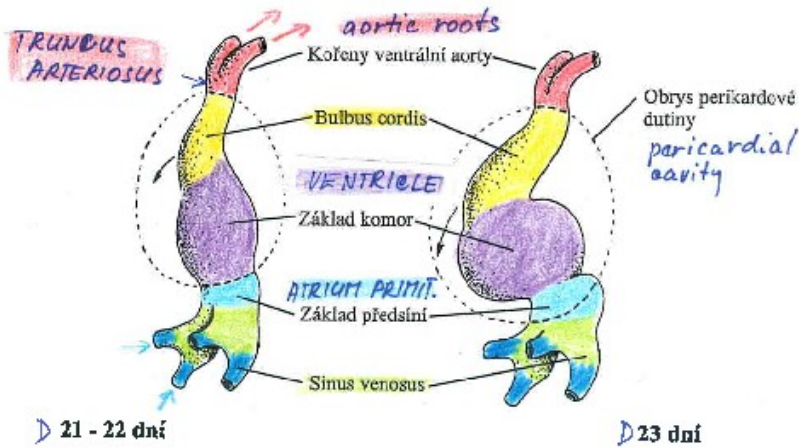
Common cardinal veins

Umbilical veins

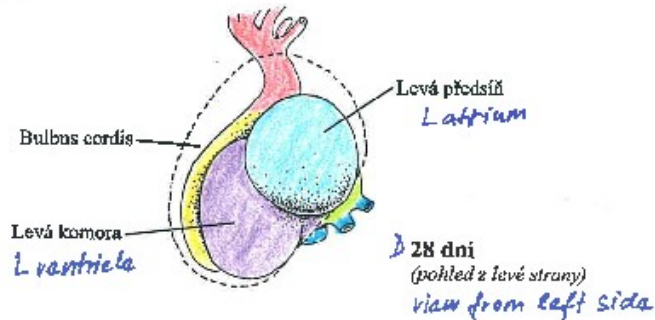
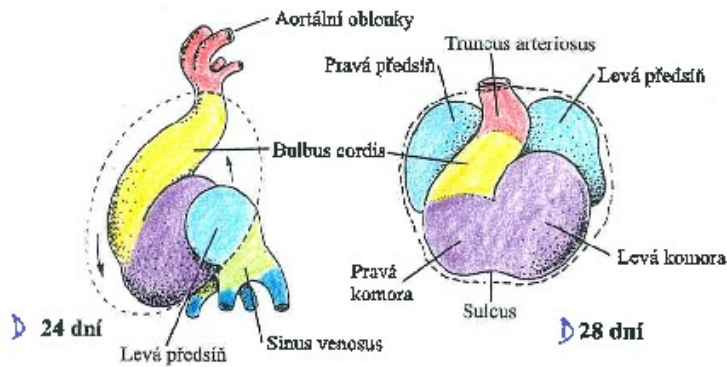
Vitelline veins

left veins obliterate and
 - left portion of sinus venosus is transformed into sinus coronarius
 - right portion becomes to be part of right atrium

Truncus arteriosus + aortic roots

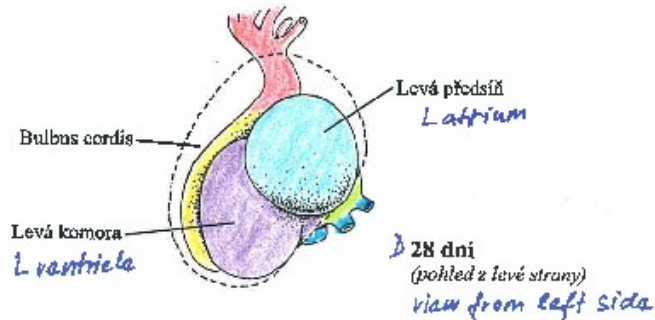
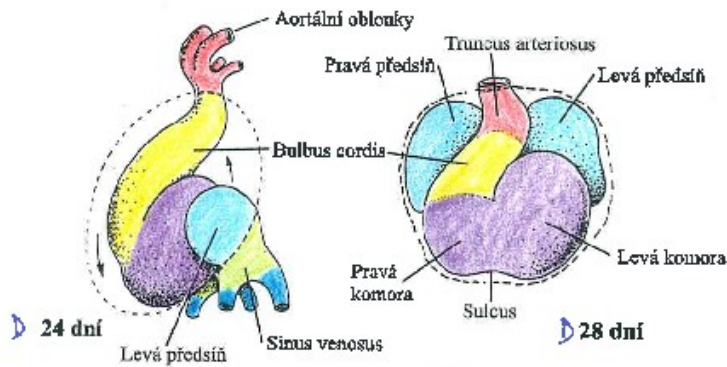
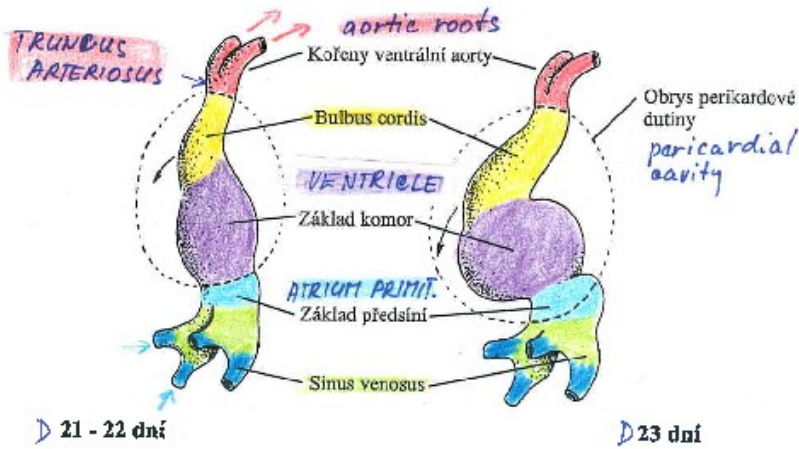


- cranial part of bulbus cordis divides into:
- aortic roots, branched into 6 pairs of aortic arches



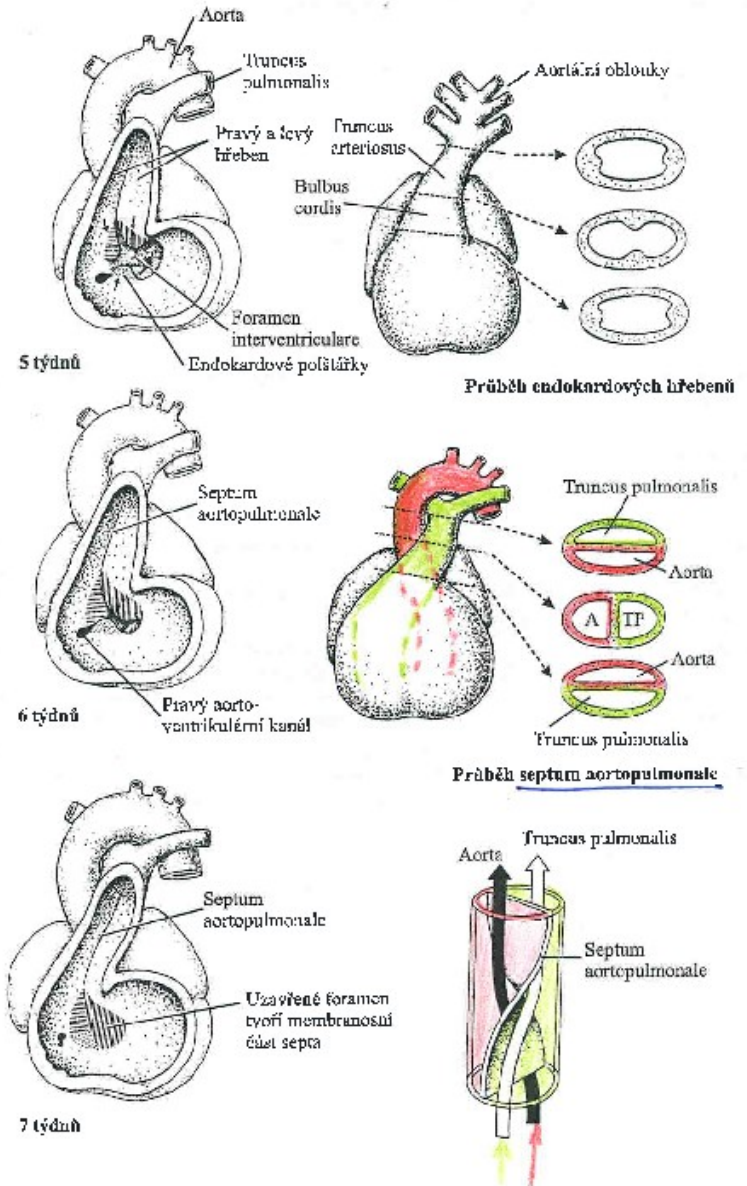
Bulbus cordis

- cranial part give rise to truncus arteriosus
- middle part give rise to conus arteriosus
- distal part participate in formation of ventricle wall

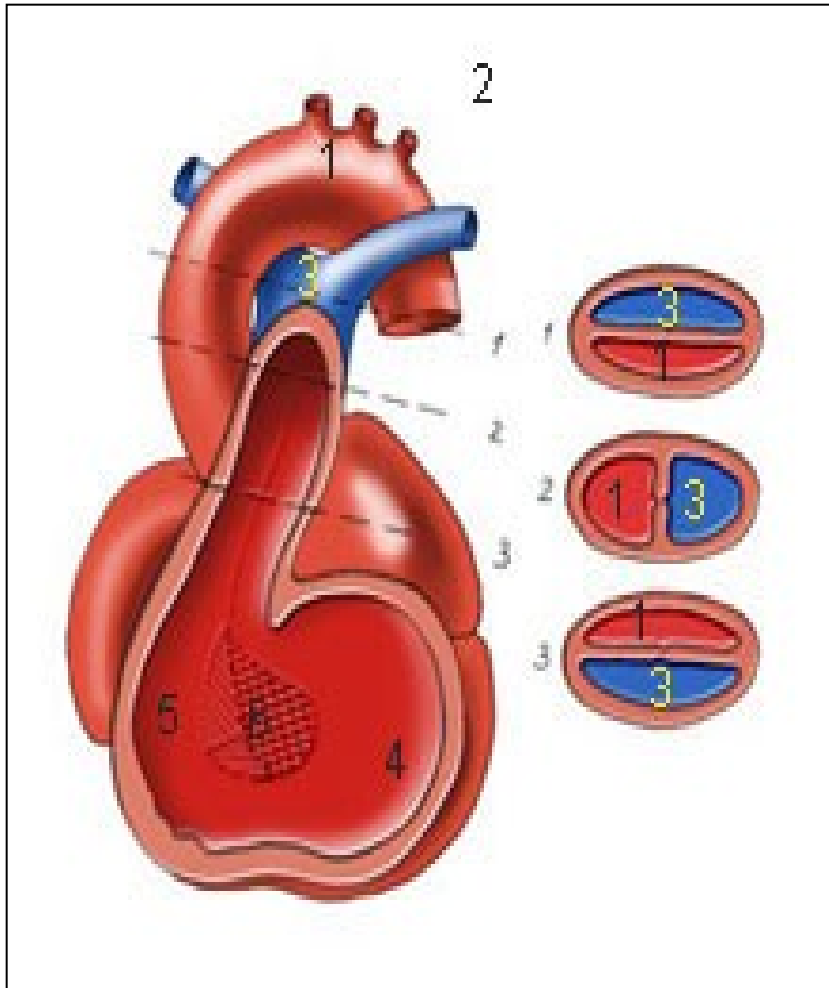


Bulbus cordis and truncus arteriosus

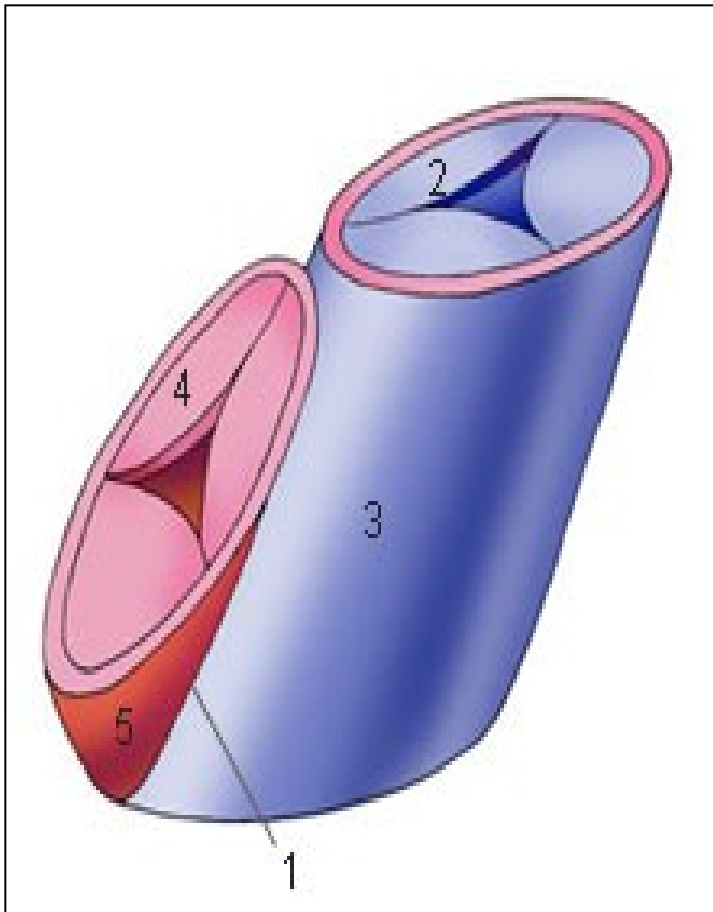
a pair of opposing ridges appear in the walls of the bulbus cordis and truncus arteriosus. These ridges twist around each other, forming a spiral course of the **aortico-pulmonary septum**. This septum divides the bulbus cordis and truncus arteriosus into two channels, the **aorta** and the **pulmonary artery**. It also participates in the closure of the interventricular foramen



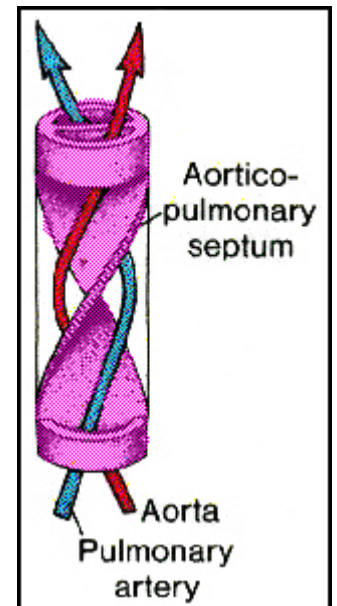
Formation of aortopulmonary septum

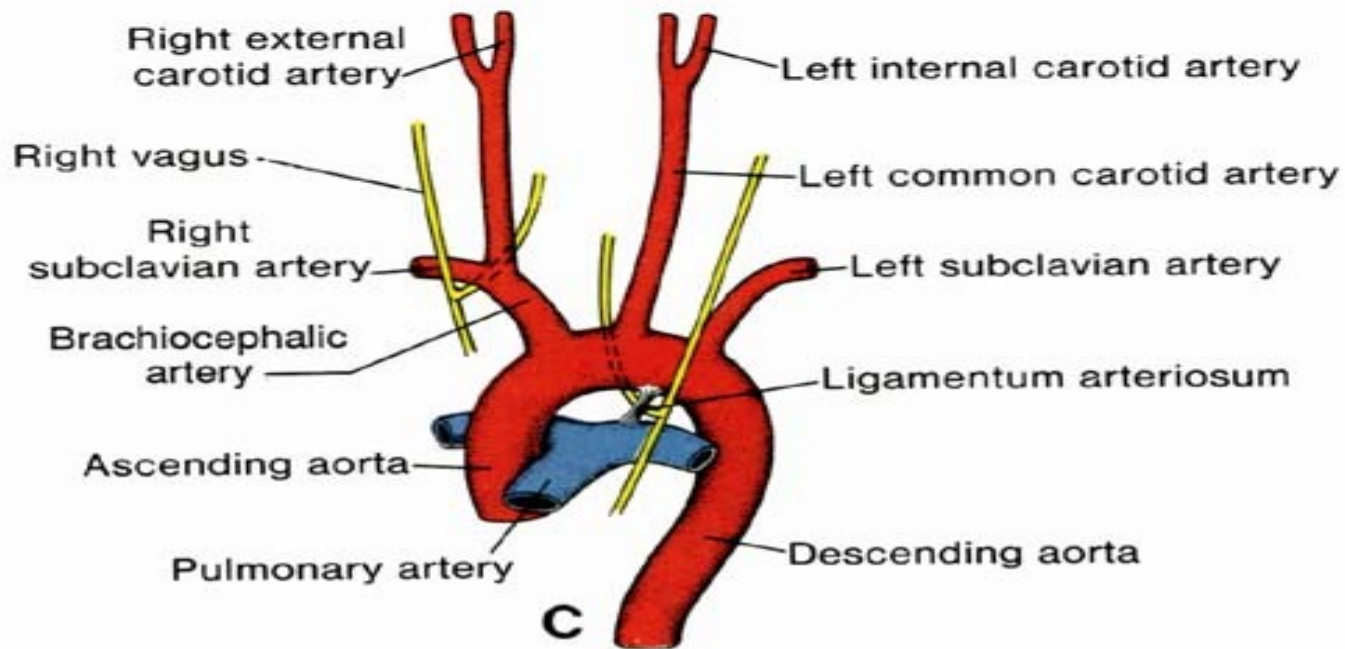
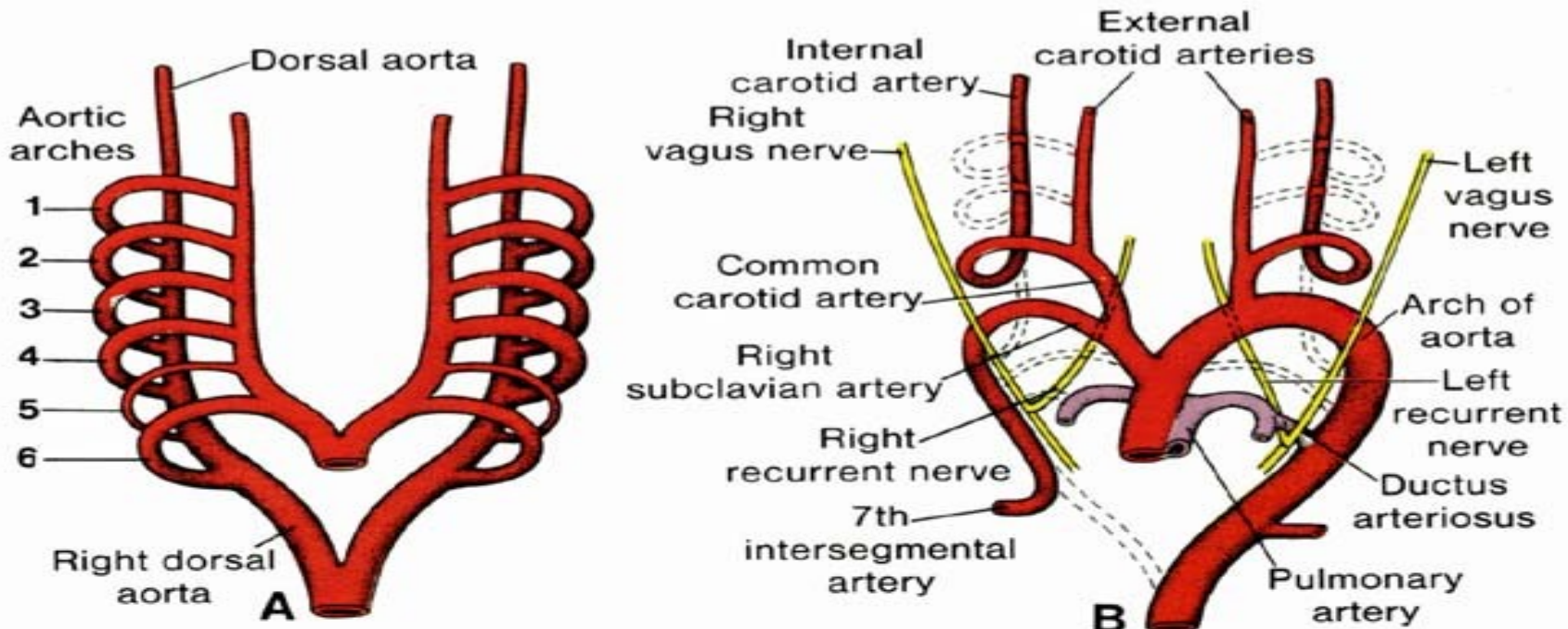


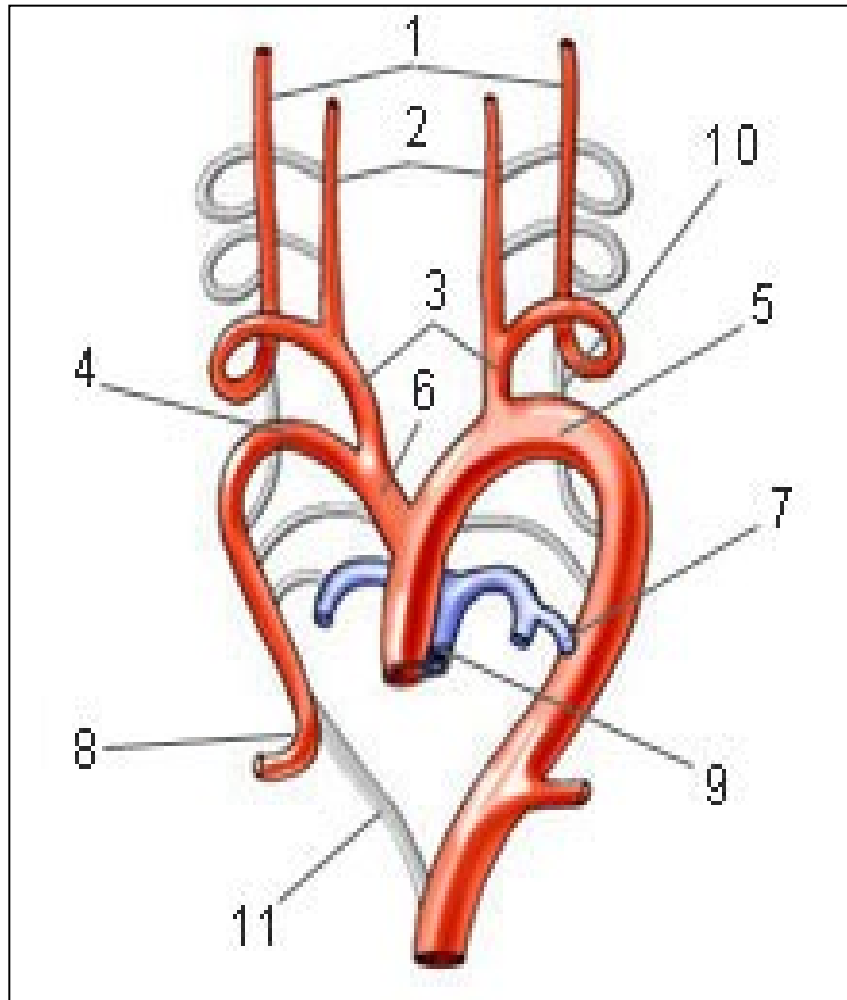
1. **Aorta**
2. Left pulmonary artery
3. **Pulmonary trunk**
4. Muscular interventricular septum
5. Right ventricle
6. Membranous interventricular septum



1. Aorticopulmonary septum
2. Pulmonary valve
3. Pulmonary artery
4. Aortic valve
5. Aorta



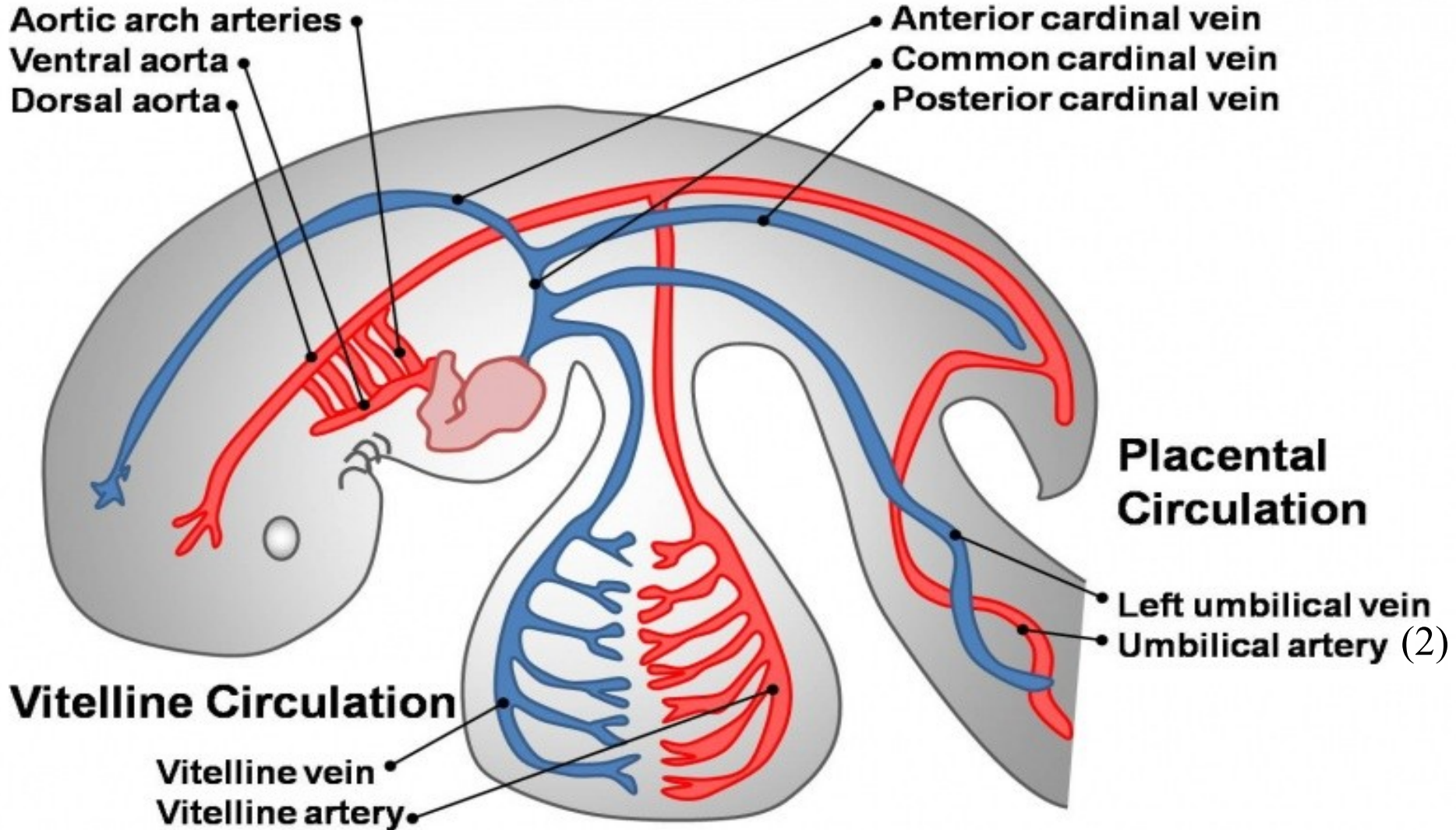




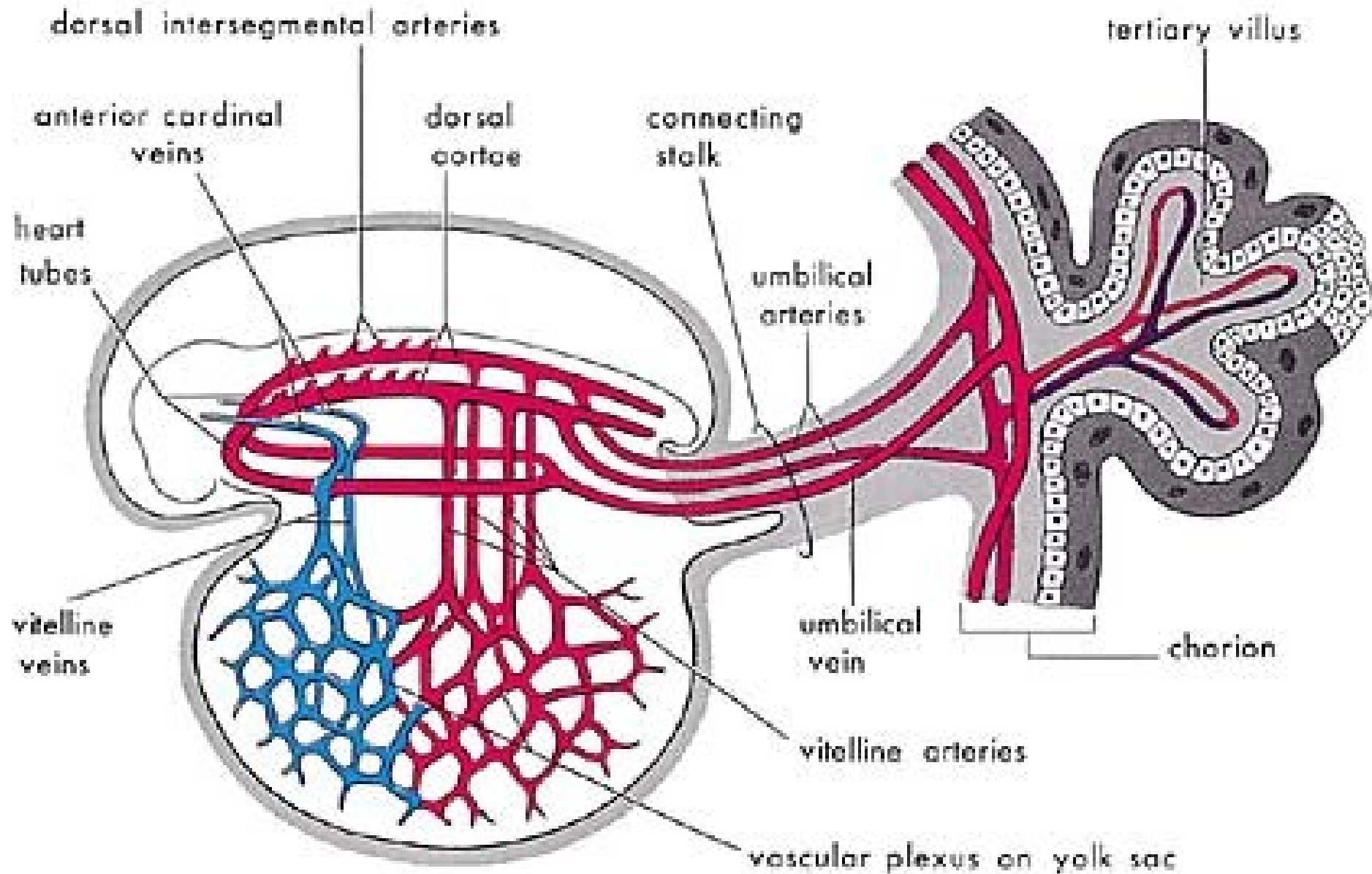
1. Internal carotid artery
2. External carotid artery
3. Common carotid artery
4. Right subclavian artery
5. Arch of aorta
6. Brachiocephalic artery
7. Ductus arteriosus
8. 7th intersegmental artery
9. Pulmonary artery
10. Carotid duct
11. Obliterated right dorsal aorta

Primitive blood circulation

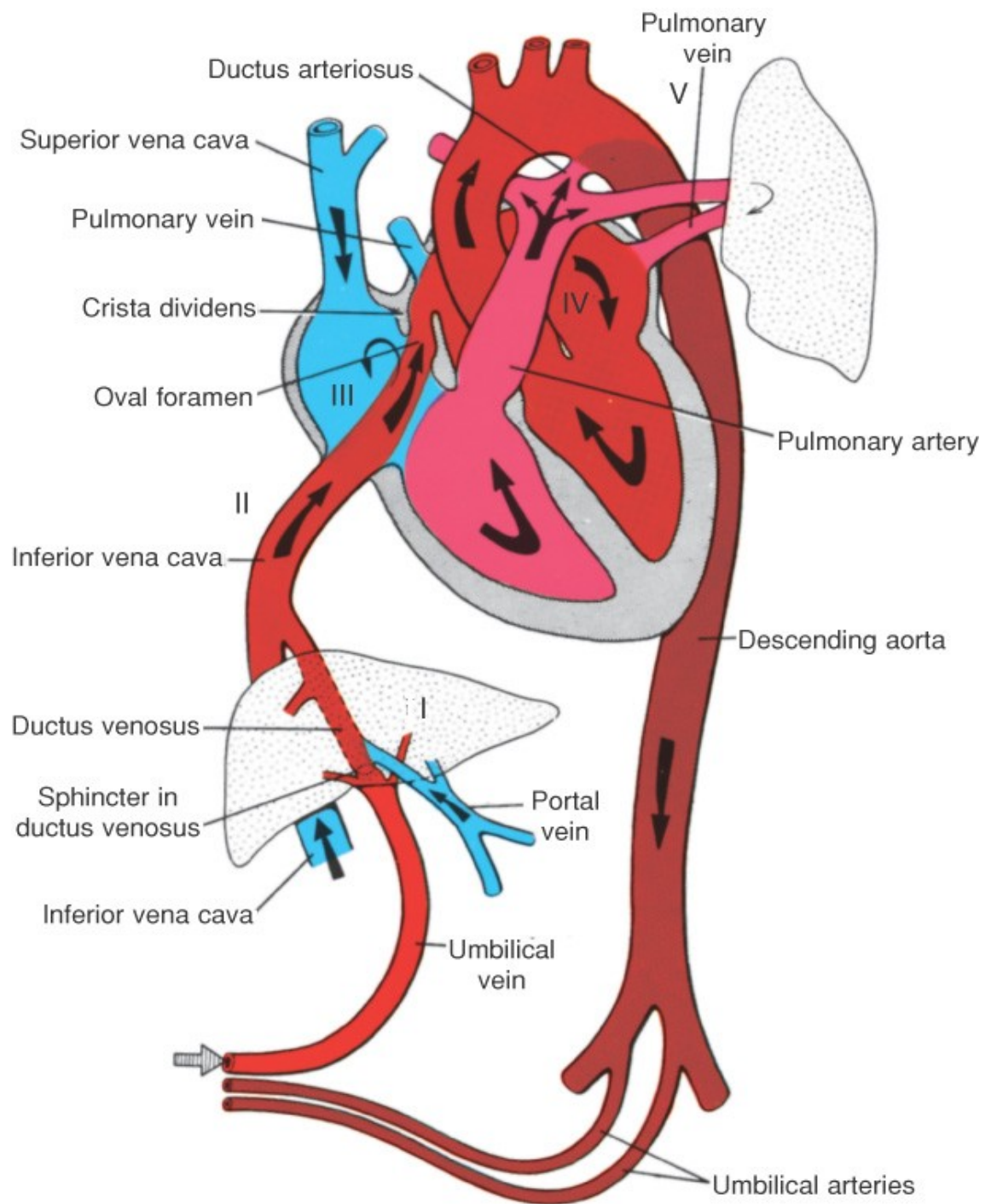
Embryonic Circulation



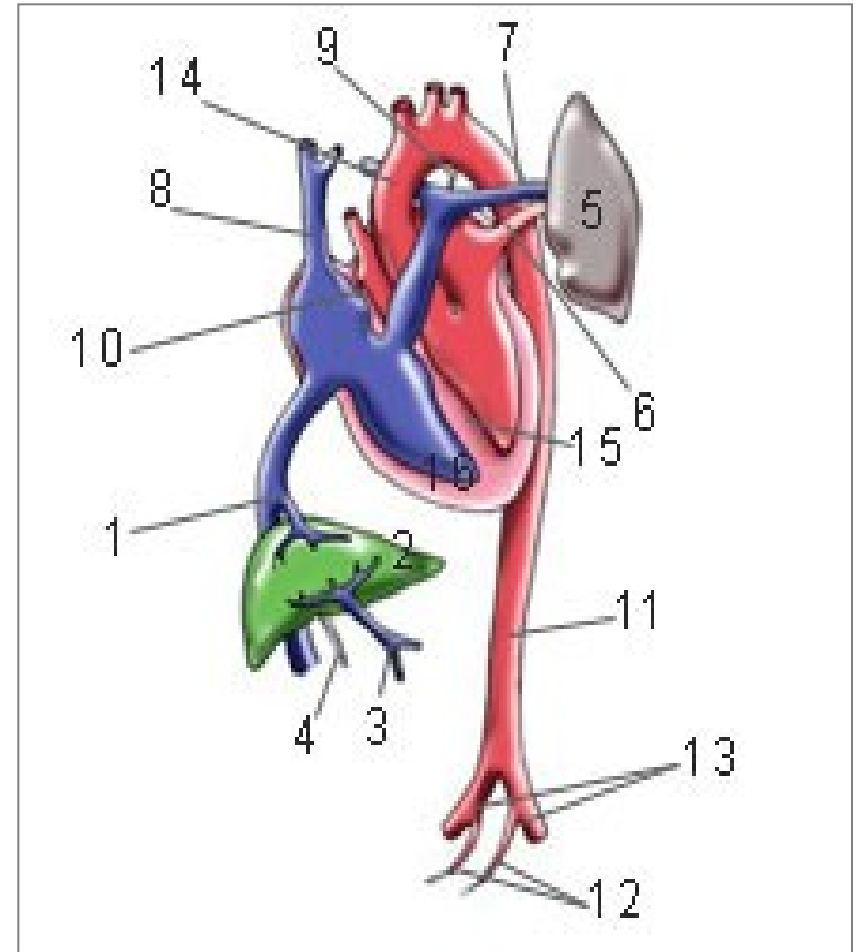
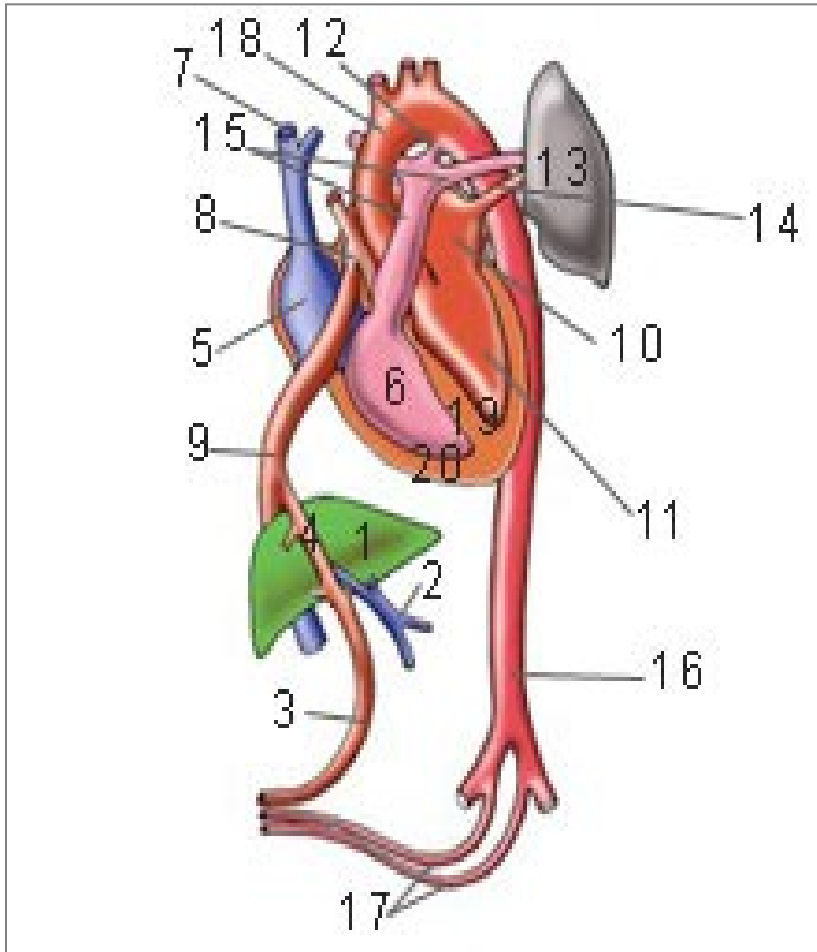
the primitive blood circulation in an embryo.



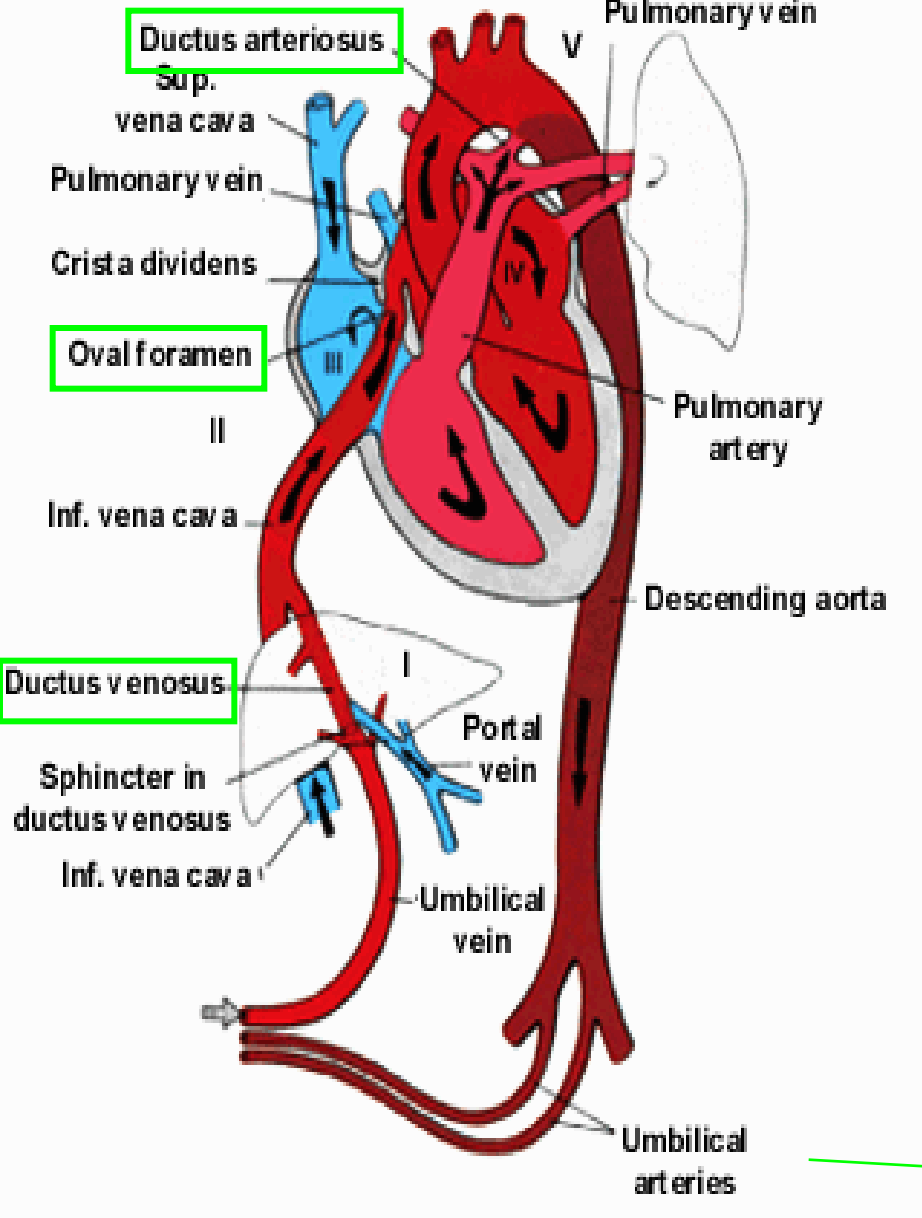
The fetal circulation



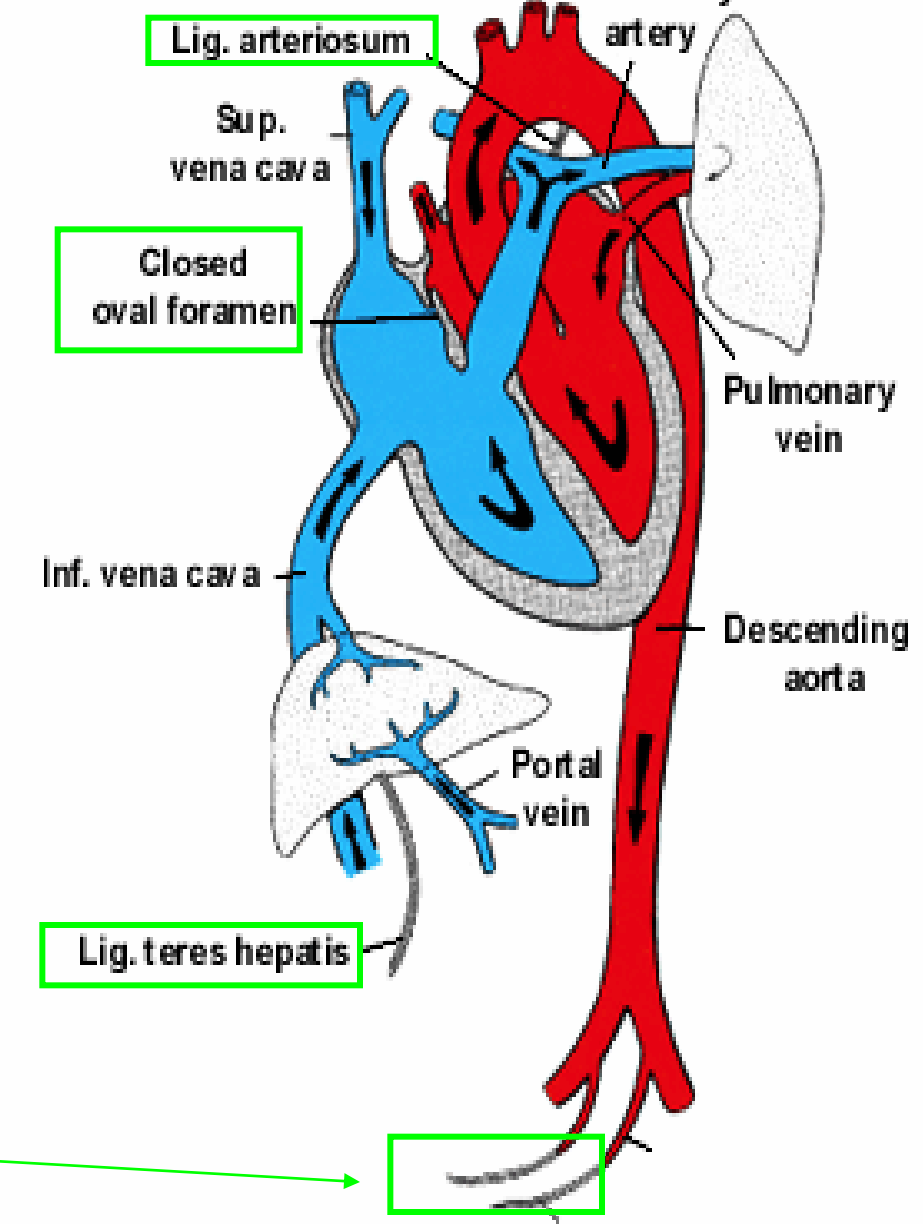
At birth, the circulation of the fetal blood through the placenta is stopped and the lungs begin to function. The foramen ovale, ductus arteriosus, ductus venosus and umbilical vessels subsequently obliterate and transform into corresponding ligaments.



Pre-Birth



Post-Birth



Congenital malformations in CVS

(the most frequent)

- **With left → right shunt (without cyanosis)**

atrial septum defect

ventricular septum defect

ductus arteriosus apertus (patens, persistens)

- **With right → left shunt (with cyanosis)**

Fallot tetralogy

transposition of great vessels

truncus arteriosus (common aortopulmonary canal)

tricuspid valve atresia

- **Without shunt**

coarctation of aorta

aortic stenosis

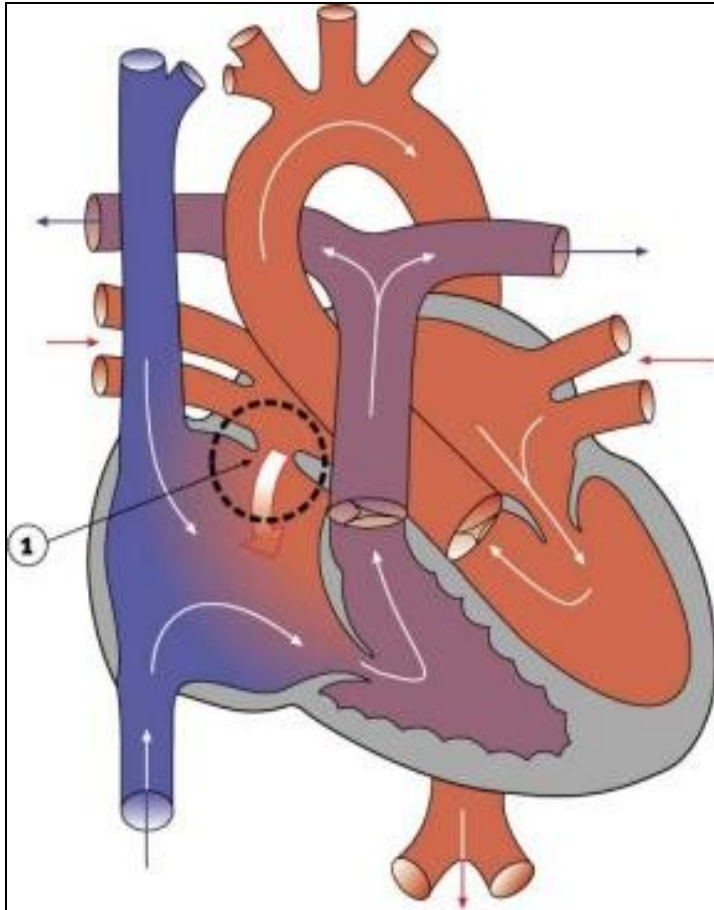
pulmonary stenosis

dextrocardia (+situs inversus)

ectopia cordis

Atrial Septal Defects

a group of common congenital anomalies defects occurring in a number of different forms and more often in females.

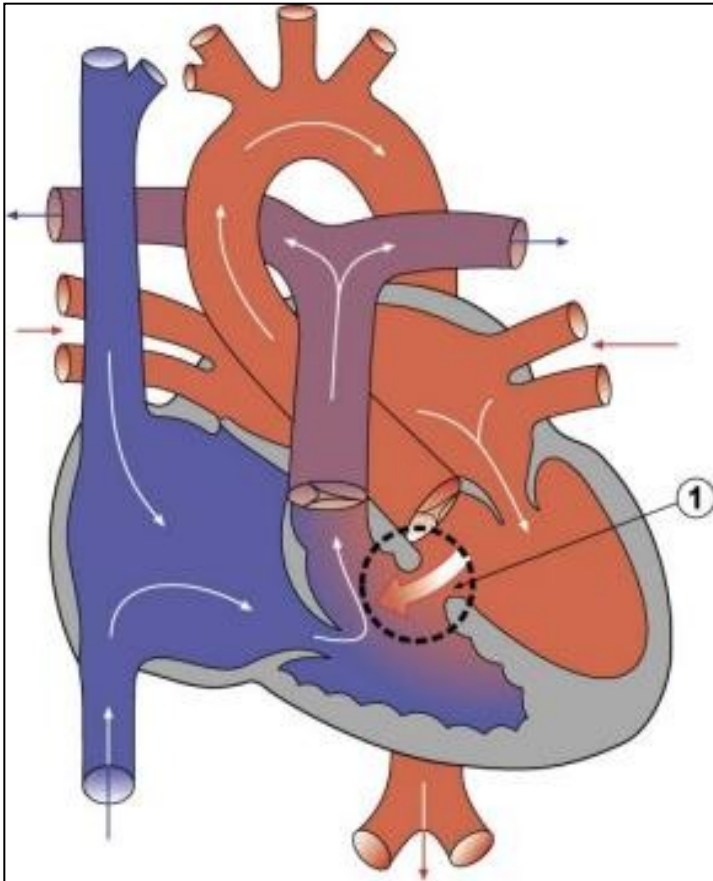


patent foramen ovale

left-right shunting

Ventricular Septal Defect

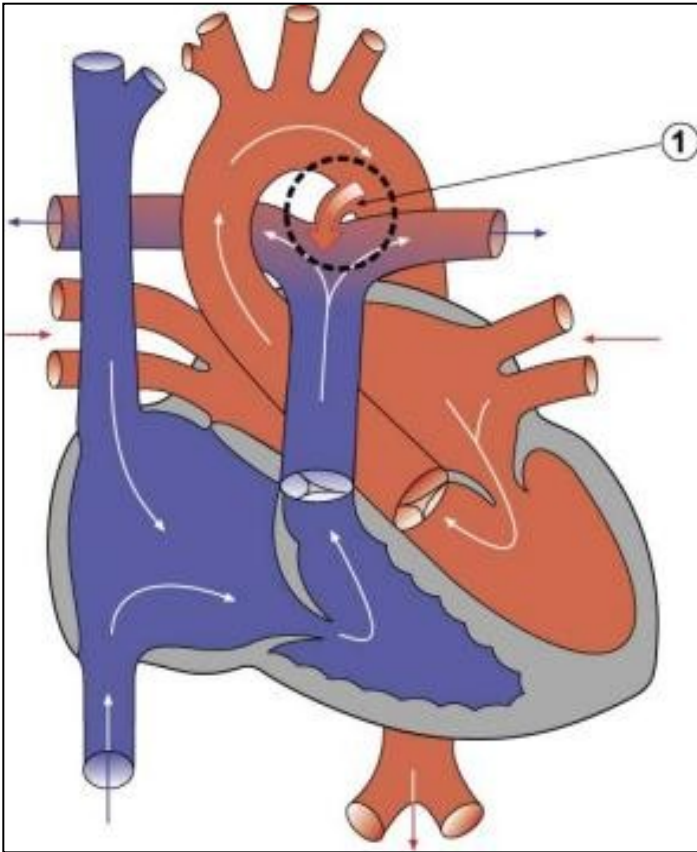
occurs in the interventricular septum, and is more frequent in males than females.



left-right shunting

Patent Ductus Arteriosus

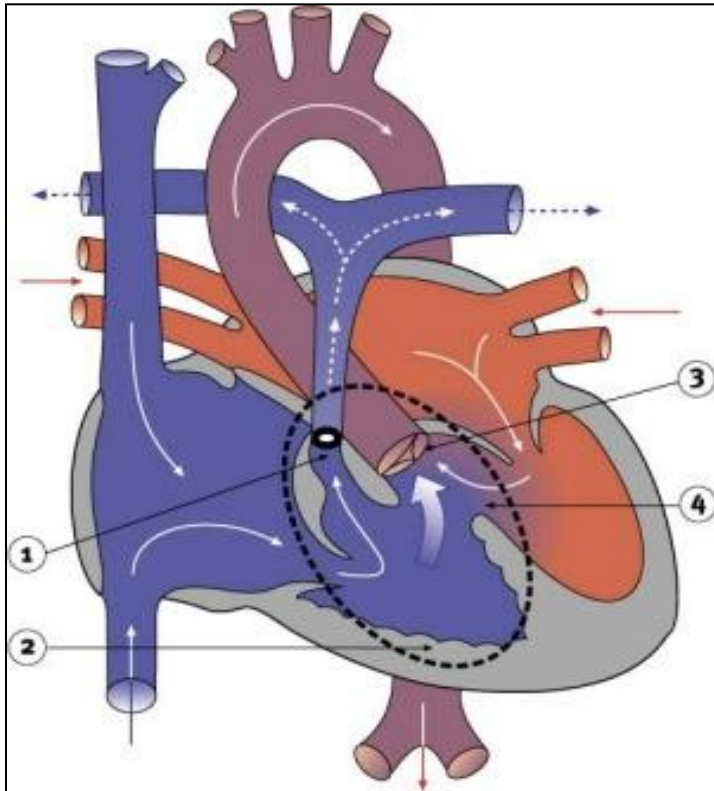
occurs commonly in preterm infants, can close spontaneously (by day three in 60% of normal term neonates) the remainder are ligated simply and with little risk.



left-right shunting

Tetralogy of Fallot

named after Etienne-Louis Arthur Fallot (1888) who described it as "*la maladie blue*" and is a common developmental cardiac defect. The syndrome consists of a number of cardiac defects possibly stemming from abnormal neural crest migration.



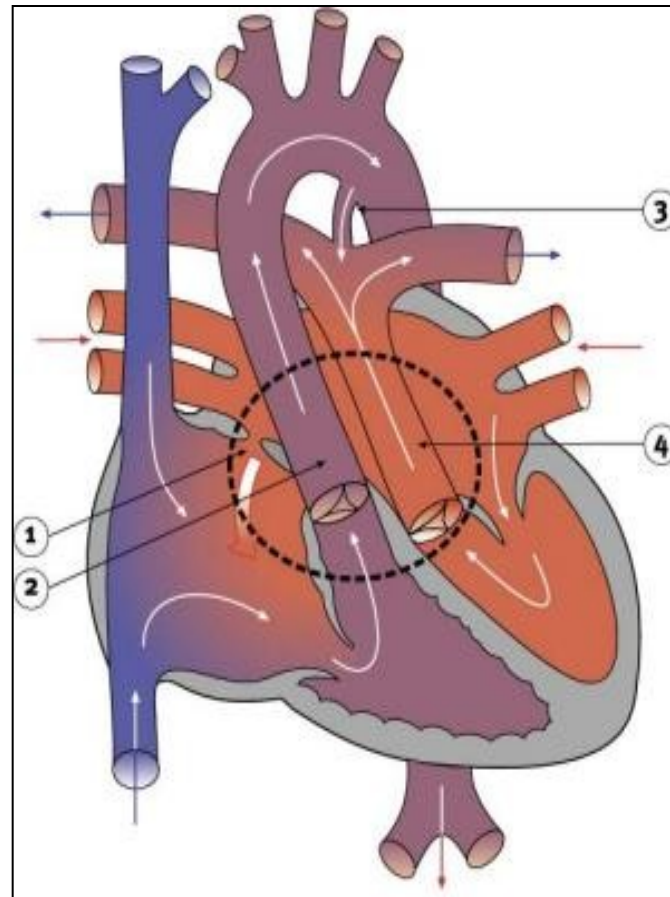
consists of:

1. ventricular septal defect
2. pulmonary stenosis (valvular or infundibular)
3. results in an overriding aorta
4. right ventricular hypertrophy

right-left shunting

Transposition of Great Vessels

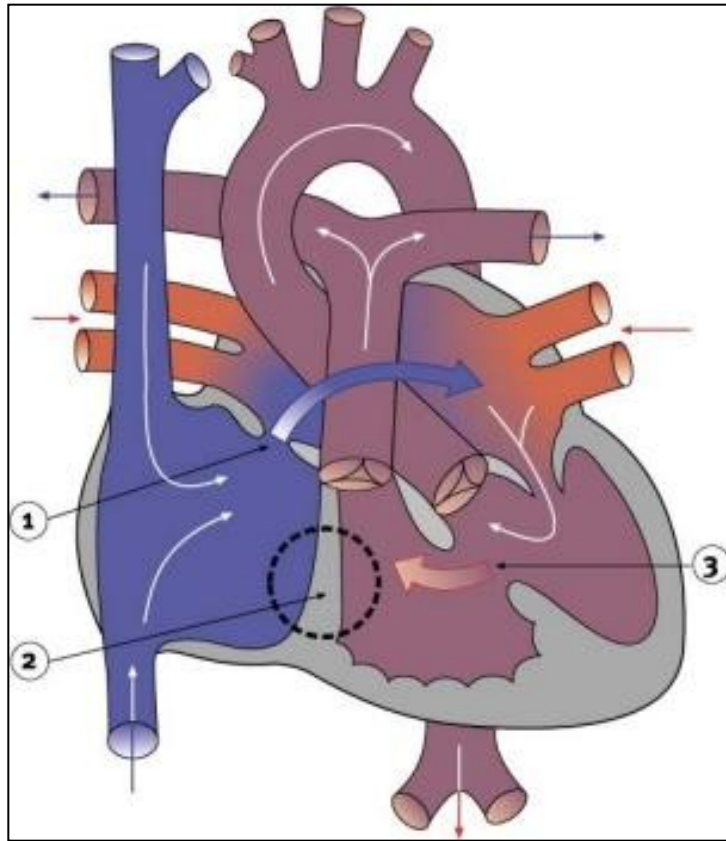
Characterized by aorta arising from right ventricle and pulmonary artery from the left ventricle and often associated with other cardiac abnormalities (e.g. ventricular septal defect).



right-left shunting

Tricuspid Atresia

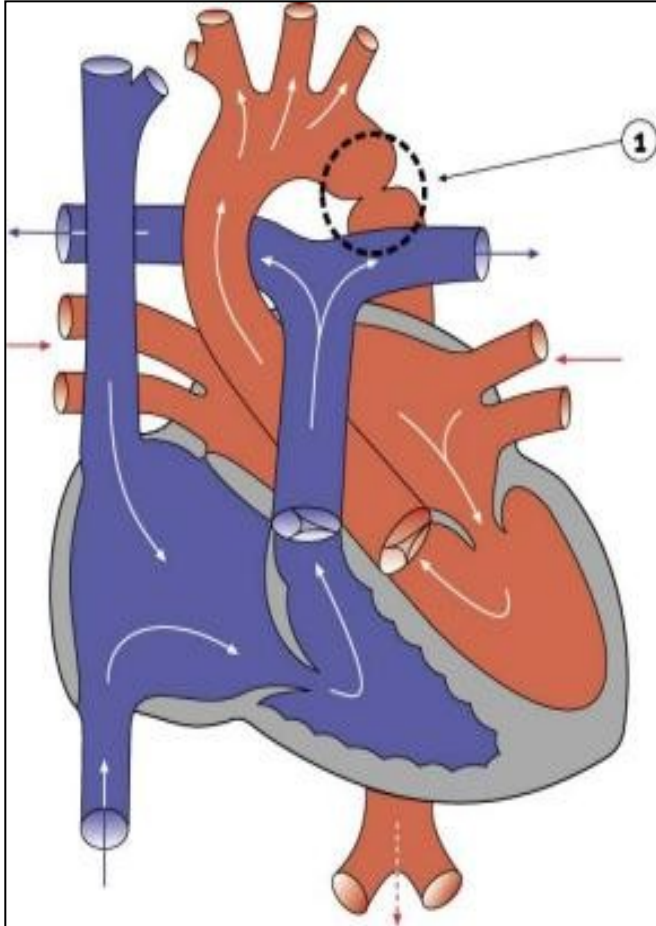
Blood is shunted through an atrial septal defect to the left atrium and through the ventricular septal defect to the pulmonary artery. The shaded arrows indicate mixing of the blood.



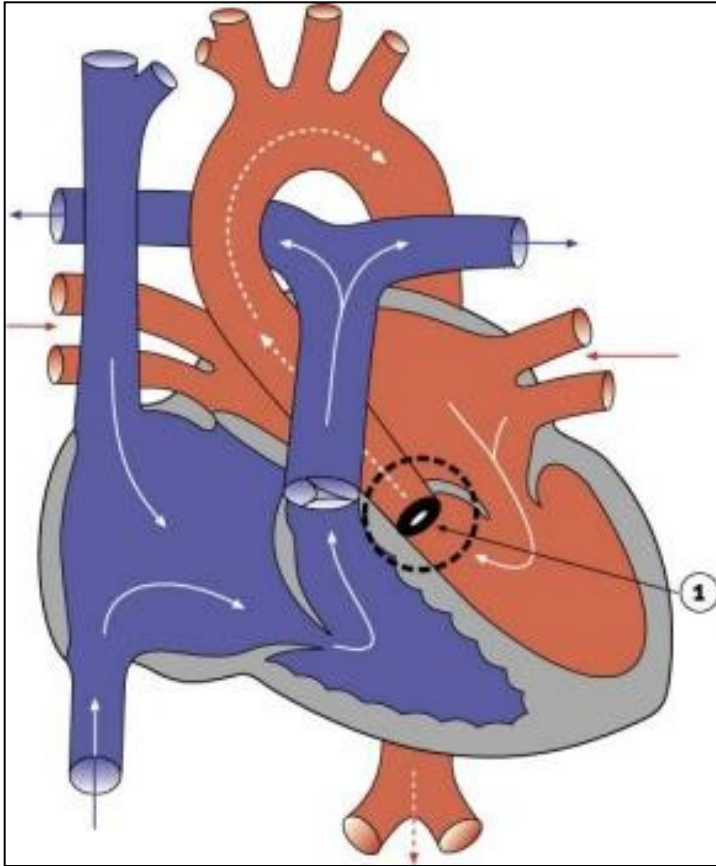
right-left shunting

Coarctation of Aorta (preductal or postductal)

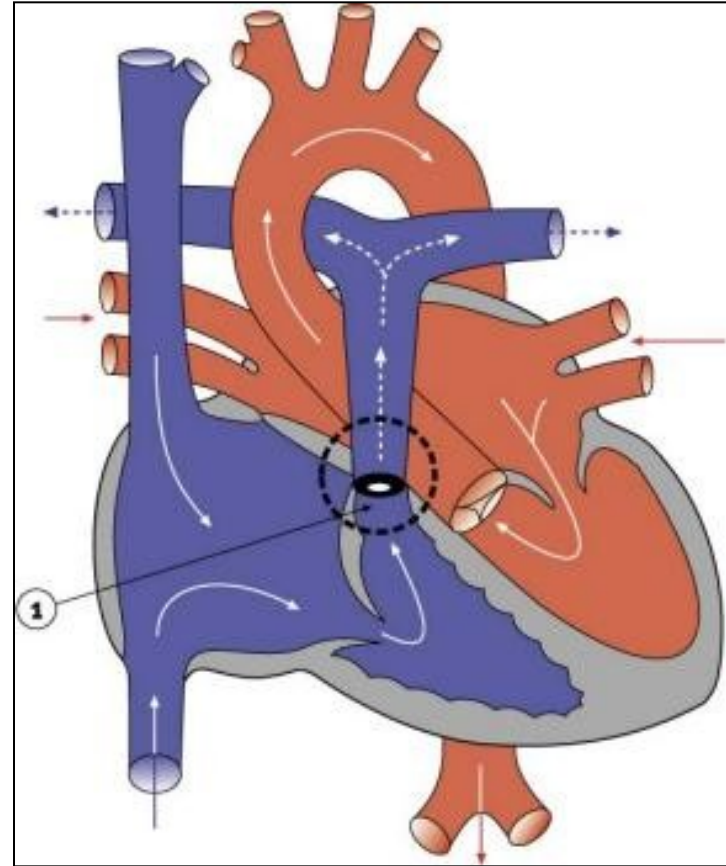
before or behind ductus arteriosus



Aortic Stenosis

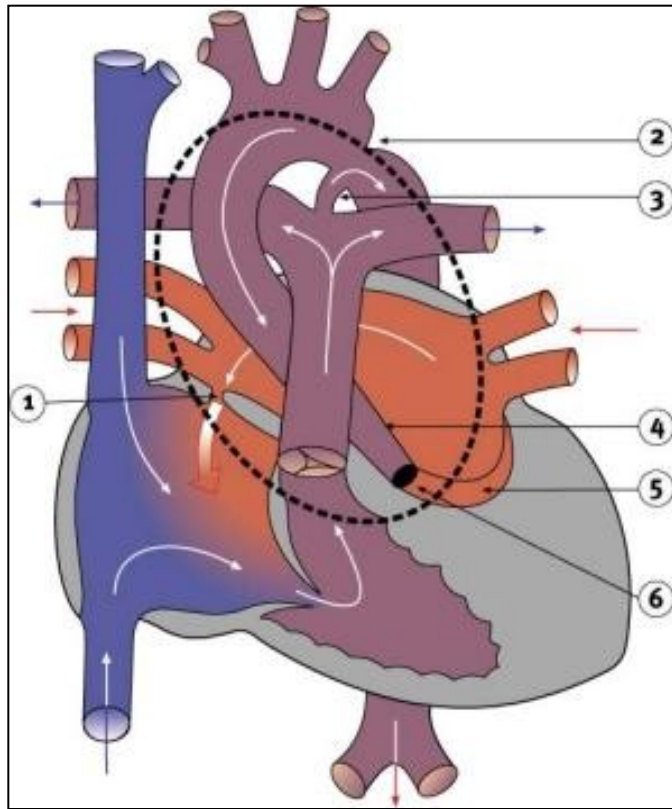


Pulmonary Stenosis

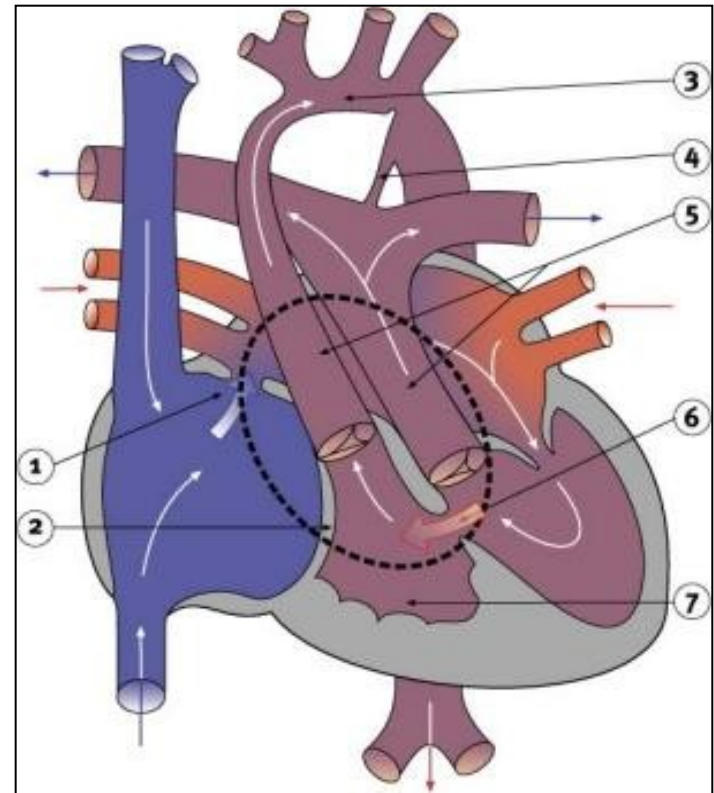


Hypoplastic Left Heart

Characterized by hypoplasia (underdevelopment or absence) of the left ventricle obstructive valvular and vascular lesion of the left side of the heart.



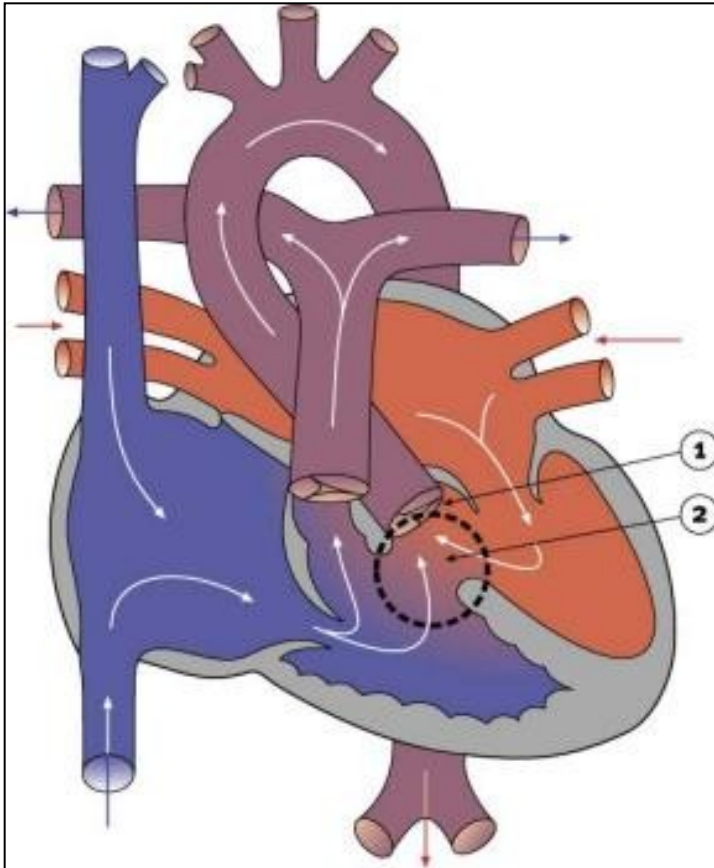
hypoplastic left hear



functional hypoplastic left heart

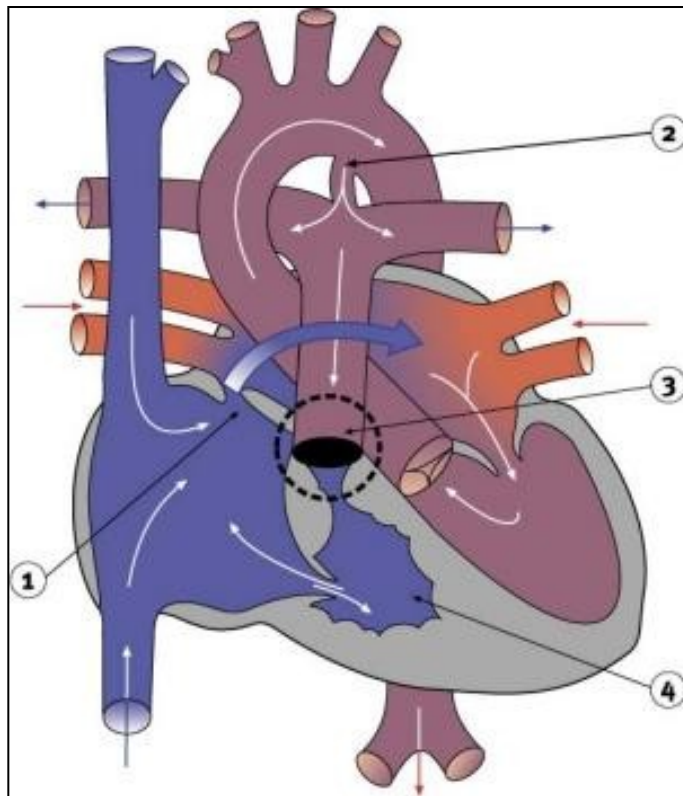
Double Outlet Right Ventricle

De-oxygenated blood enters the aorta from the right ventricle and is returned to the body.



Pulmonary Atresia

Abnormal blood flow (as indicated by the shaded blue arrow) is from the right atrium and right ventricle through an atrial septal defect to the left side of the heart. Blood can reach the pulmonary arteries only through a patent ductus arteriosus.



Heart

Sinus venosus (R horn): smooth part of right atrium (sinus venarum) and the "valve" of the superior vena cava. The sino-atrial node.

Sinus venosus (L horn): coronary sinus, valve of coronary sinus

Valve of sinus venosus (R): border of smooth part of right atrium (crista terminalis)

Valve of sinus venosus (L): part of atrial septum

Common atrium: rough part of right and left atria and the auricles

Embryonic pulmonary vein: large part of the left atrial wall

Septum primum: left side of the atrial septum

Septum secundum: right side of the atrial septum

Foramen secundum: dimple in the atrial septum seen from left side (fossa ovalis, ok)

Foramen ovale: fossa ovalis

Endocardial cushions: parts of the atrioventricular wall, mitral, and tricuspid valves

Endocardial cushions: membraneous part of ventricular septum, part of arterial trunk

Bulbus cordis: trabeculated part of R ventricle and aortic vestibule of L ventricle

Truncus arteriosus: ascending (ventral) aorta and pulmonary artery

Common ventricle: parts of the right and left ventricle

Arterial System

Aortic sac (R and L sides of sac): brachiocephalic artery (right) and part of the ascending aorta (left), large parts of common carotid arteries

1st aortic arch (R and L): part of the maxillary artery and external carotid arteries

2nd aortic arch (R and L): part of the hyoid and stapedial arteries, part of external carotids

3rd aortic arch (R and L): part of common carotids and first part of the internal carotids

4th aortic arch (R): small proximal part of the right subclavian artery

4th aortic arch (L): small part of arch of the aorta just proximal to the left subclavian artery

6th aortic arch (R): proximal part of right pulmonary artery

6th aortic arch (L=ductus): proximal left pulmonary artery and and ligamentum arteriosum

Ductus arteriosus: ligamentum arteriosum

Dorsal aorta (R and L): part of right subclavian, descending aorta below left subclavian

Unpaired ventral (or vitelline) arteries: celiac, superior mesenteric, and inferior mesenteric arteries

Paired dorsal segmental arteries: intercostal arteries and vertebral arteries

Umbilical arteries: internal iliac, superior vesical arteries, medial umbilical ligaments

Venous System

Ductus venosus: ligamentum venosum

Umbilical vein (L): round ligament (ligamentum teres)

Vitelline vein (R): superior mesenteric vein and the inferior vena cava

Vitelline vein (L): most of the portal vein

Anterior cardinal veins (R and L): internal jugular veins (left brachiocephalic vein is an anastomosis)

Anterior cardinal vein (R): part of superior vena cava and right brachiocephalic vein

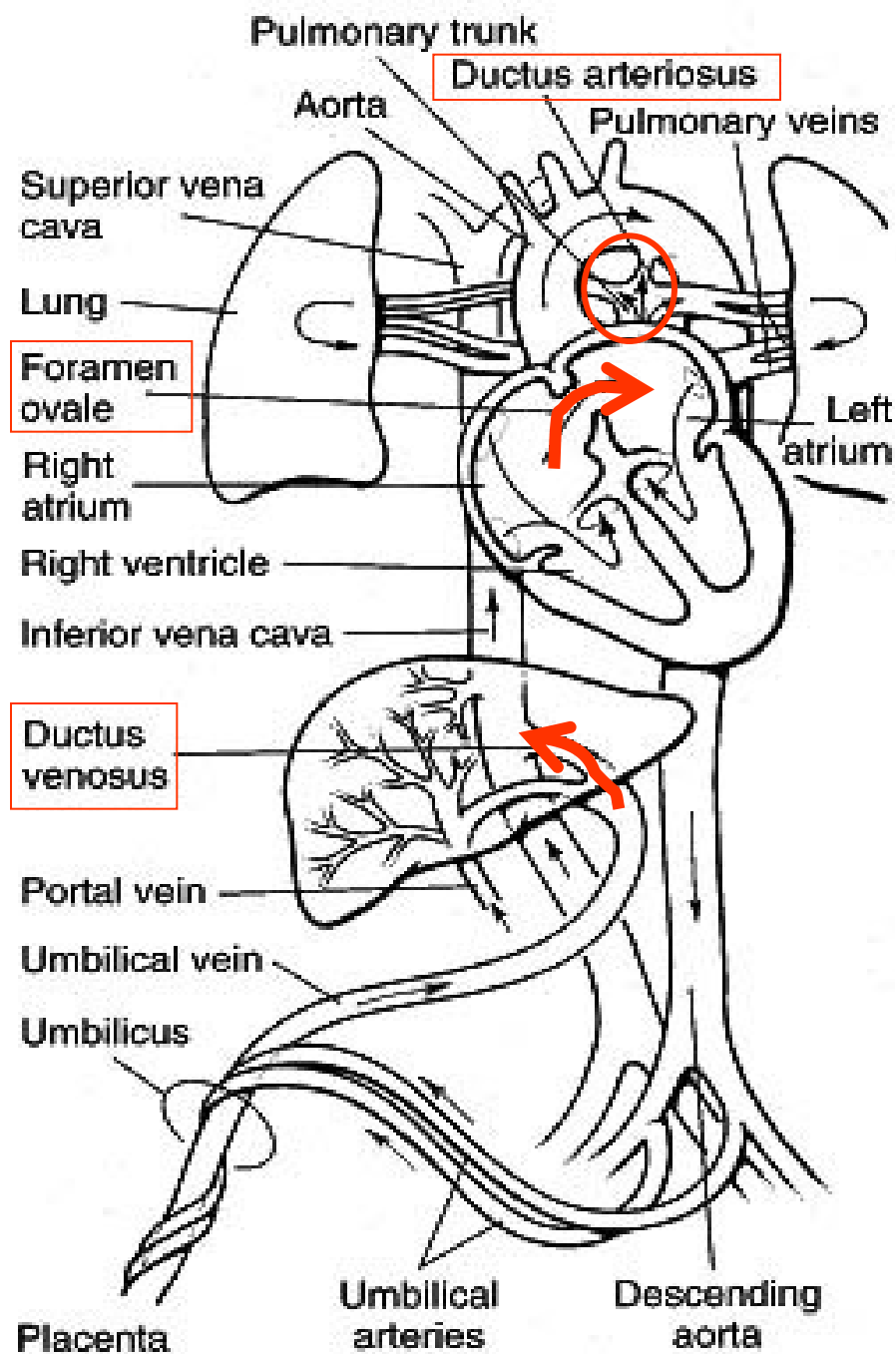
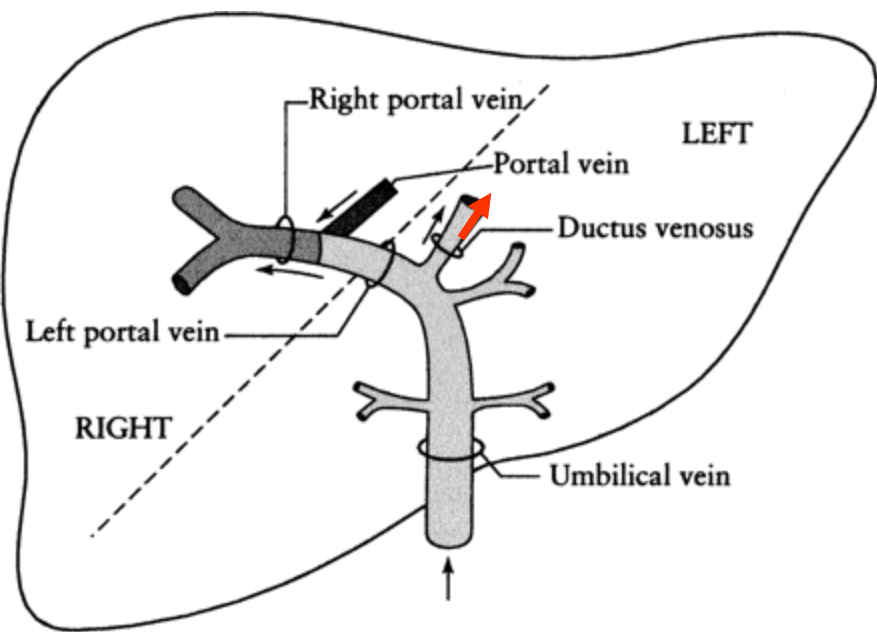
Common cardinal vein (R): proximal part of superior vena cava

Common cardinal vein (L): lateral part of coronary sinus and oblique vein of left atrium

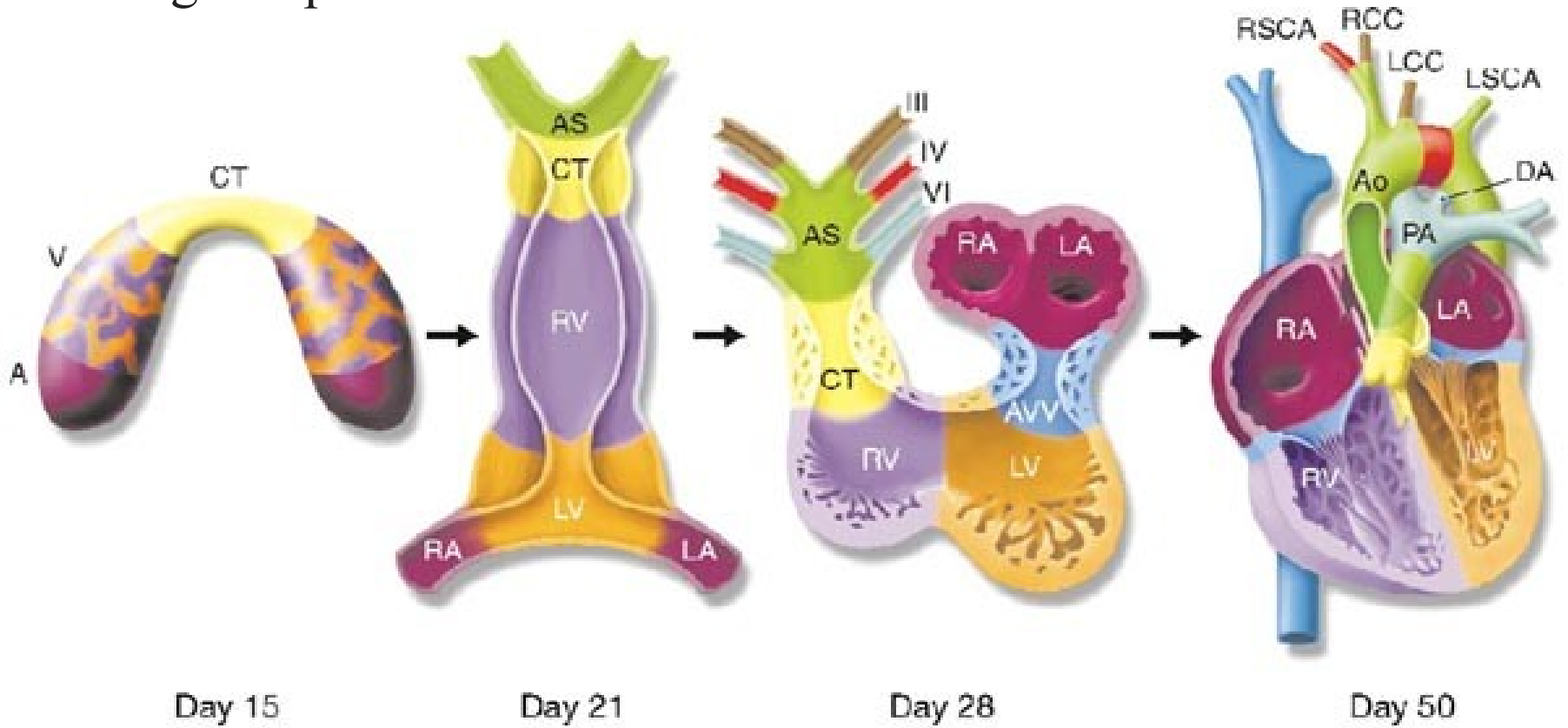
Posterior cardinal vein (R): part of azygos vein and common iliac veins

Supracardinal veins: hemiazygos vein (L) and caudal part of azygos vein (R)

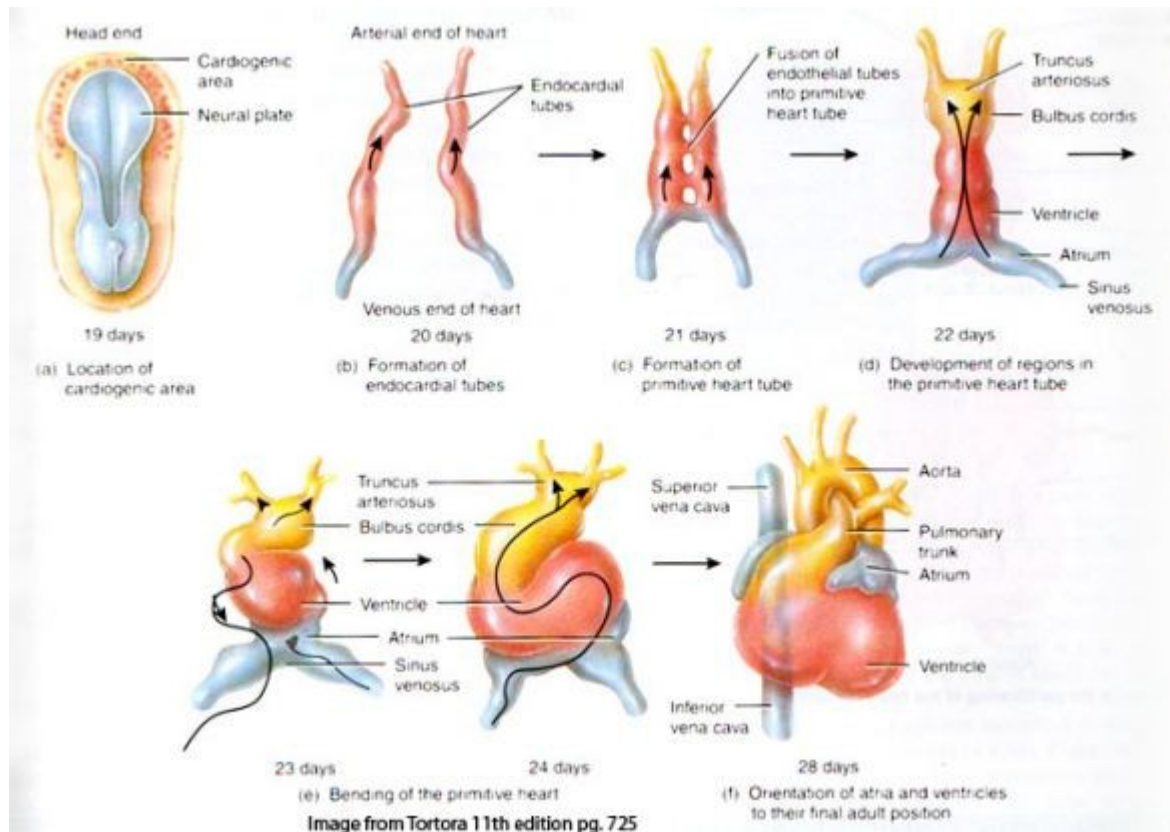
Subcardinal vein (R): renal segment of inferior vena cava

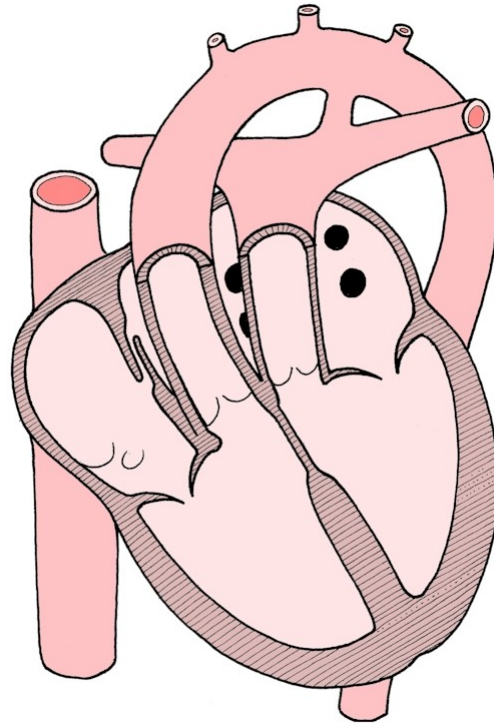


Cardiogenic precursors form the linear heart tube.



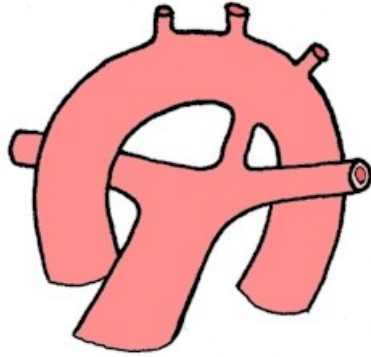
Mesenchymal cells form the cardiac valves from the conotruncal (CT) and atrioventricular valve (AVV) segments. A – atrium; Ao – aorta; DA – ductus arteriosus; LA – left atrium; LCC – left common carotid; LSCA – left subclavian artery; LV – left ventricle; PA – pulmonary artery; RA – right atrium; RCC – right common carotid; RSCA – right subclavian artery; RV – right ventricle; V – ventricle.



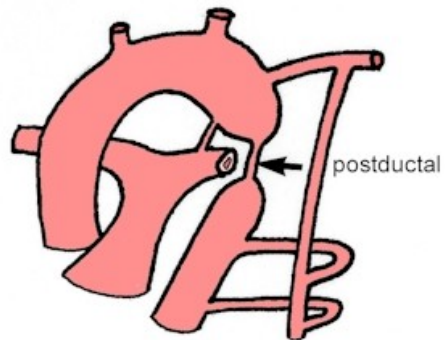
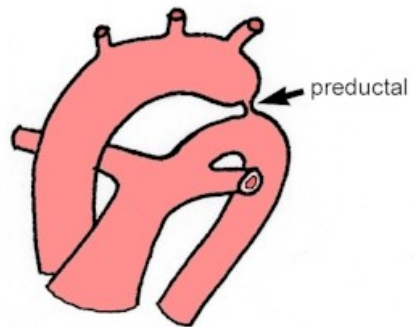


transposition of the great vessels - the aorta exits from the right ventricle, and the pulmonary trunk exits from the left ventricle. This is only compatible with life postnatally if the ductus arteriosus remains patent, allowing communication between the otherwise closed systemic and pulmonary circulations driven by the left and right sides of the heart.

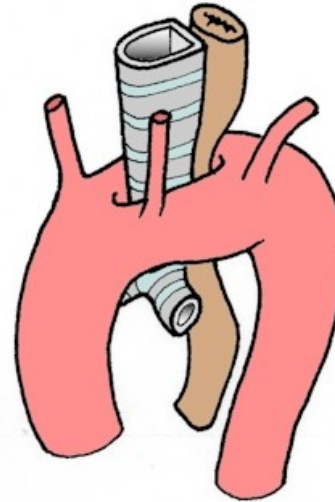
patent ductus arteriosus



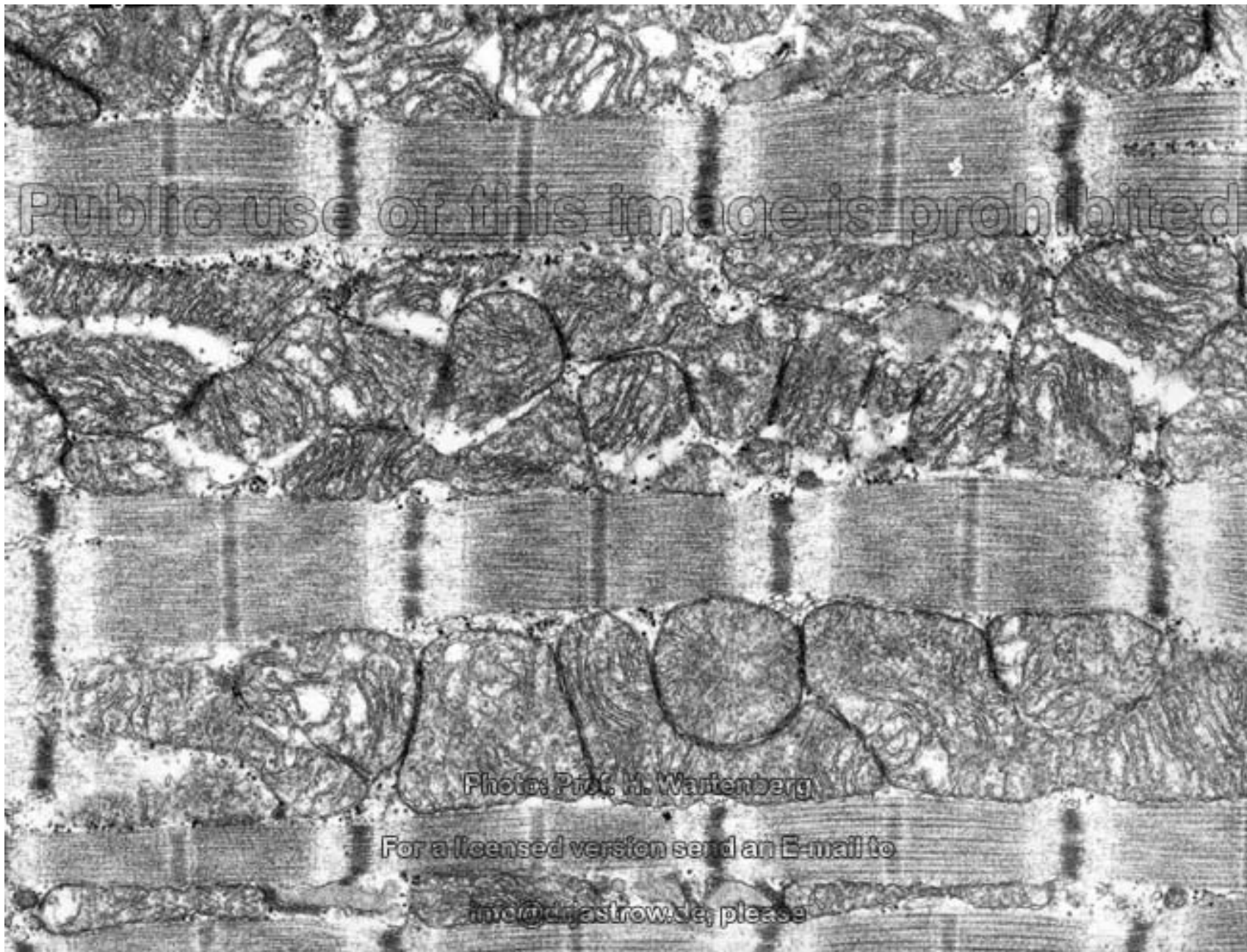
coarctation of the aorta



double aortic arch







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