VOLGOGRAD STATE MEDICAL UNIVERSITY

Department of histology, embryology, cytology

Development of the Heart

Lecture for the general medicine IInd course
english medium students

Volgograd, 2015

THE OBJECTIVES:

Describe the main features of heart development to the four-chambered system.

Describe the development of the pericardium

Describe the development of primary and secondary atrial septa and the ventricular septum.

Explain the changes occurring in the bulbis cordis and truncus arteriosus in its transformation from a single to a double tube.

Describe the developmental aberrations responsible for the following malformations: patent ductus arteriosus (P.D.A.); atrial septal defects (A.S.D.) and ventricular septal defects (V.S.D.); tetralogy of Fallot.

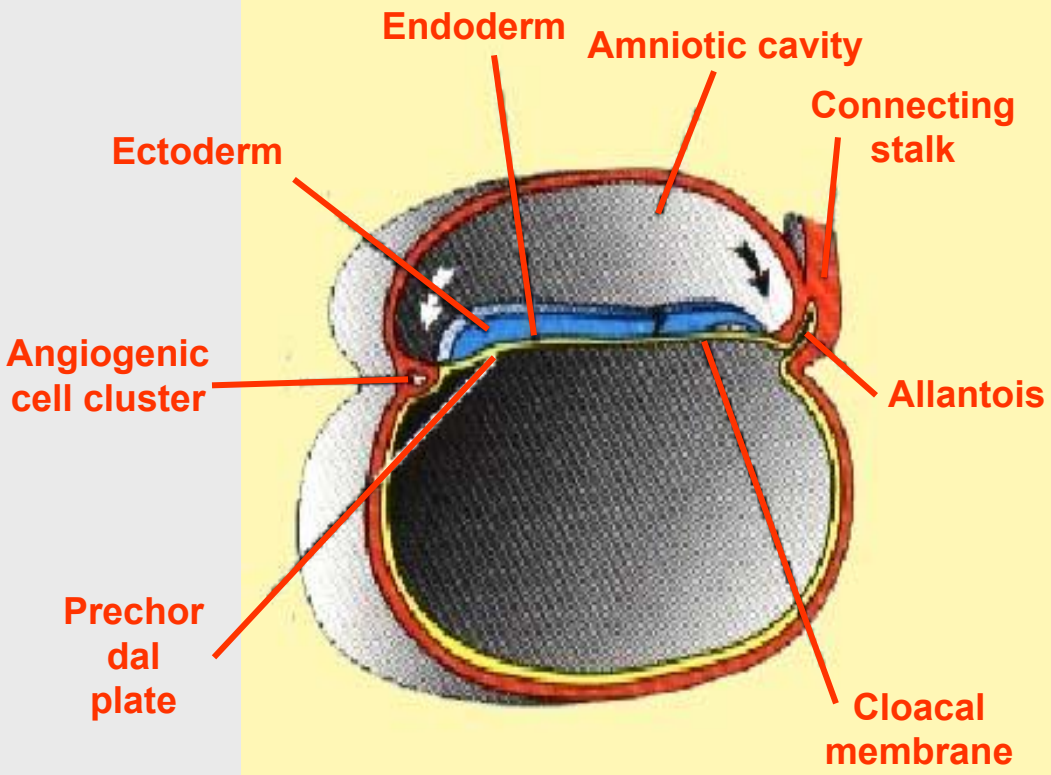
GENERAL PROVISIONS:

the CVS is the first system to function in the embryo,

vascular system appears in the middle of the 3rd week when the embryo is no longer able to satisfy its nutritional requirements by diffusion alone,

blood begins to circulate by the end of the 3rd week.

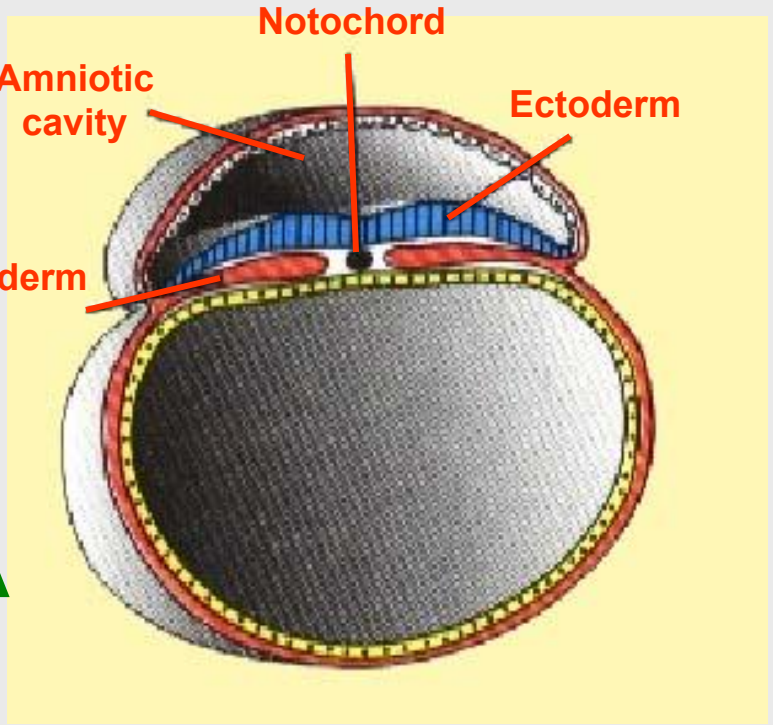
EARLY DEVELOPMENT OF THE EMBRYO

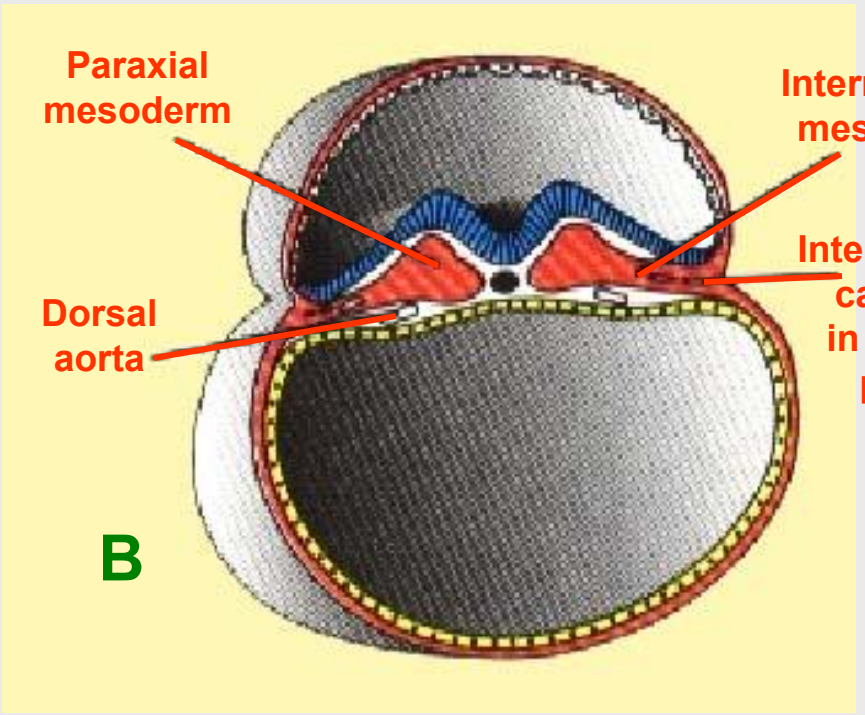


Middle of the 3rd week – presomite stage, pan-cake appearance of embryonic disc, intraembryonic endoderm constitutes the roof of the spherical yolk sac.

Formation of the angiogenic cell clusters: splanchnic mesoderm gives rise to angioblasts – cells of the mesenchymal origin condensing into interconnecting cords of cells.

DEVELOPMENT OF THE MESODERM

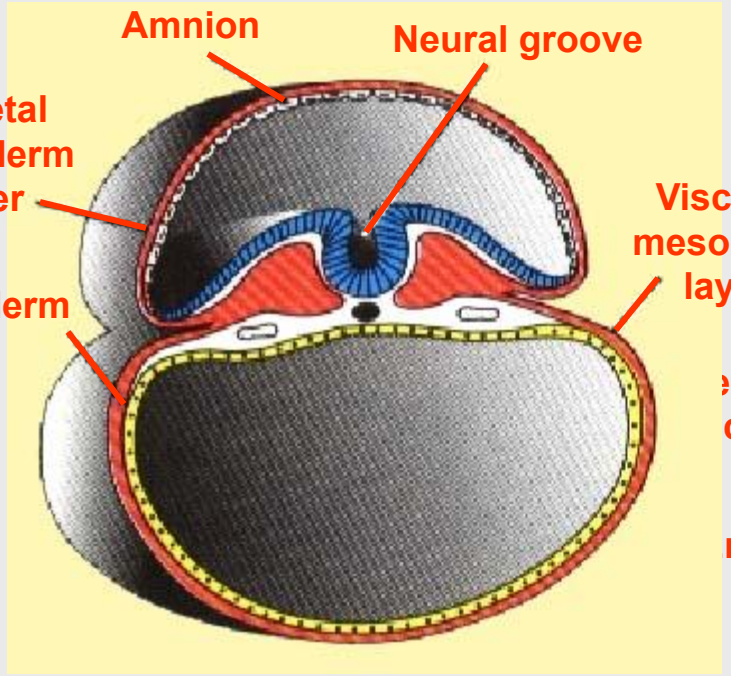


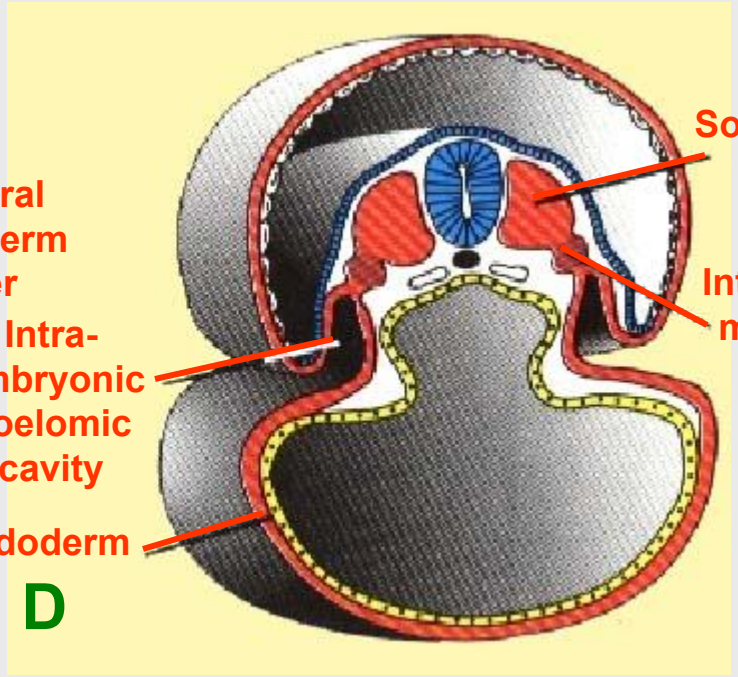


A. day 17, initially cells of the mesodermal germ layer form a thin sheet of loosely woven tissue on each side of the midline, by 17th day cells close to the midline proliferate and form a thickened plate of tissue - paraxial mesoderm.

B. day 19, more laterally, the mesoderm layer remains thin (lateral plate). Intermediate mesoderm connects paraxial and lateral plate mesoderm. Intercellular cavities in the lateral plate then appear.

DEVELOPMENT OF THE MESODERM

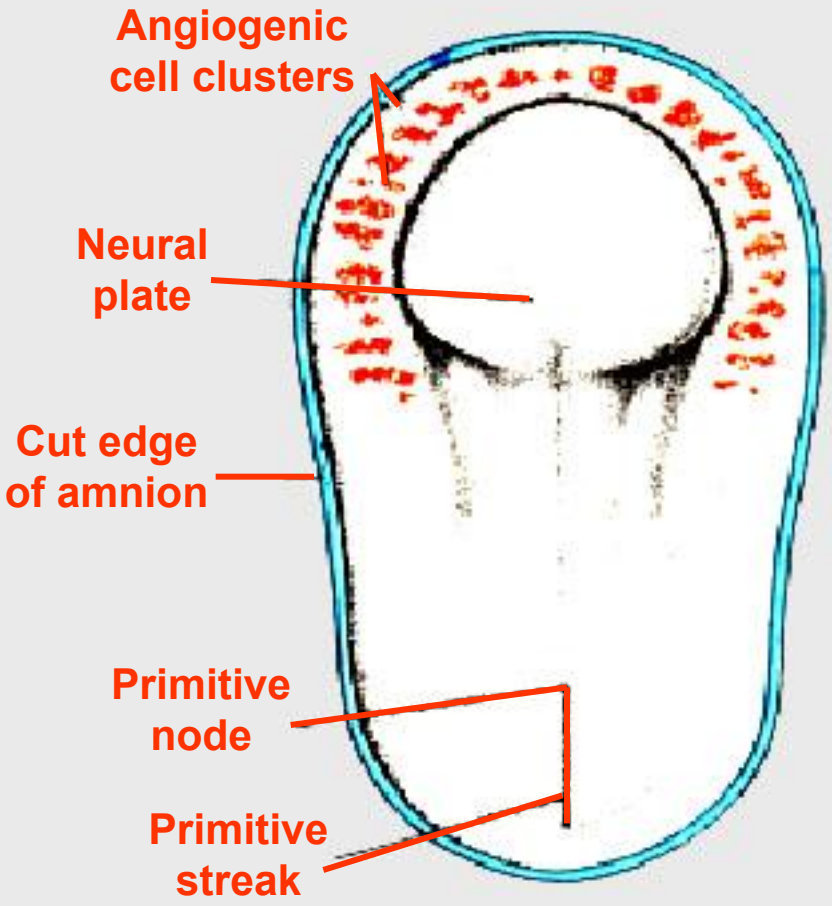




C. day 20 - intercellular cavities in the lateral plate coalesce, it is divided into two layers: the one continuous with mesoderm covering amnion (somatic or parietal mesodermal layer); and the other continuous with mesoderm covering the yolk sac (splanchnic or visceral layer).

D. day 21 - space bordered by these two layers forms a newly formed cavity, the intraembryonic coelomic cavity or body cavity, which, on each side of the embryo, is continuous with the extraembryonic coelom.

DEVELOPMENT OF THE HEART PRIMODIUM

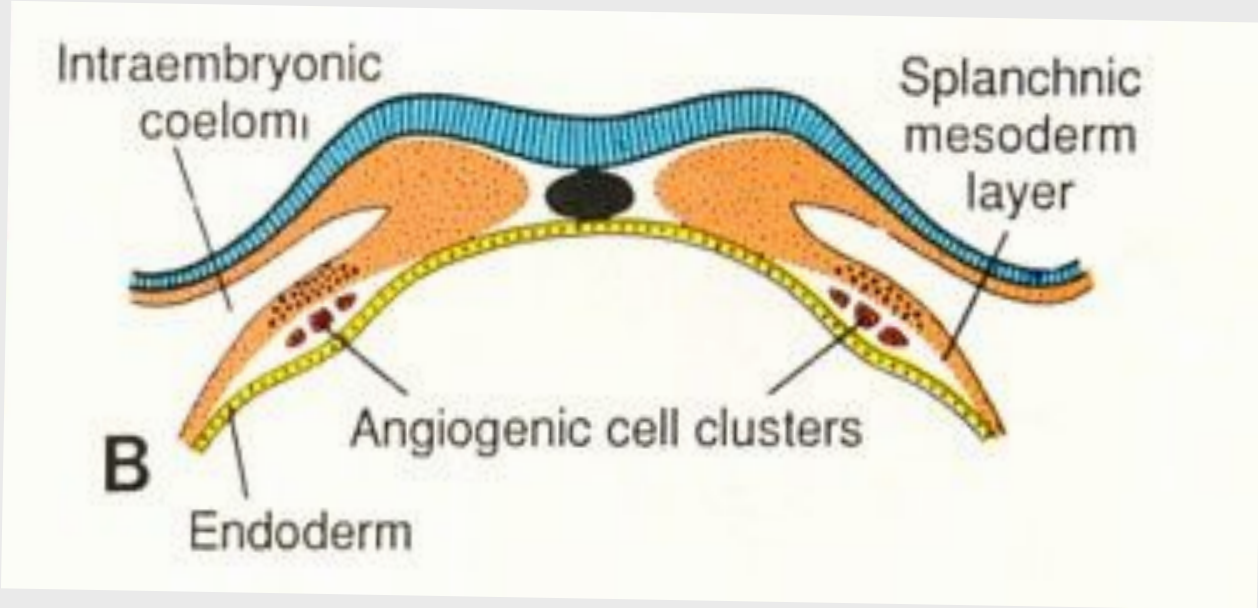


18-day old embryo

At first the angiogenic clusters are located on the lateral sides of the embryo, but they rapidly spread in a cephalic direction. The anterior central portion of these clusters is known as the cardiogenic area (region).

DEVELOPMENT OF THE PRIMITIVE HEART

19-day old embryo



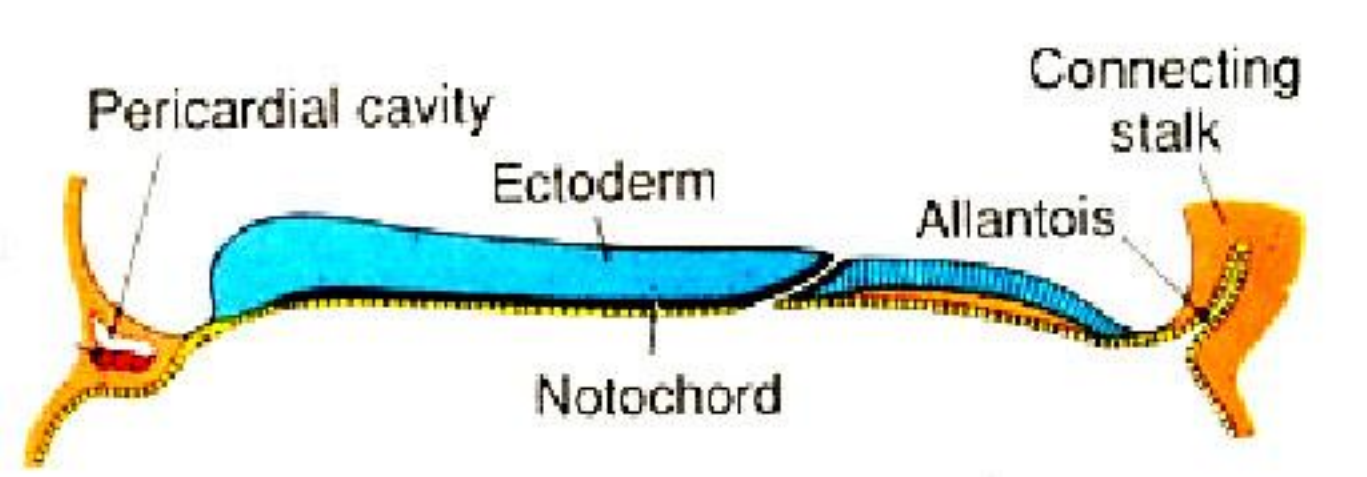
B – transverse section shows the position of the angiogenic cell clusters in the splanchnic mesoderm layer.

On day 19 a pair of vascular elements called endocardial tubes begin to develop in the cardiogenic region, a horseshoe-shaped zone of splanchnopleuric mesoderm located cranial and lateral to the neural plate on the embryonic disc.

DEVELOPMENT OF THE PRIMITIVE HEART

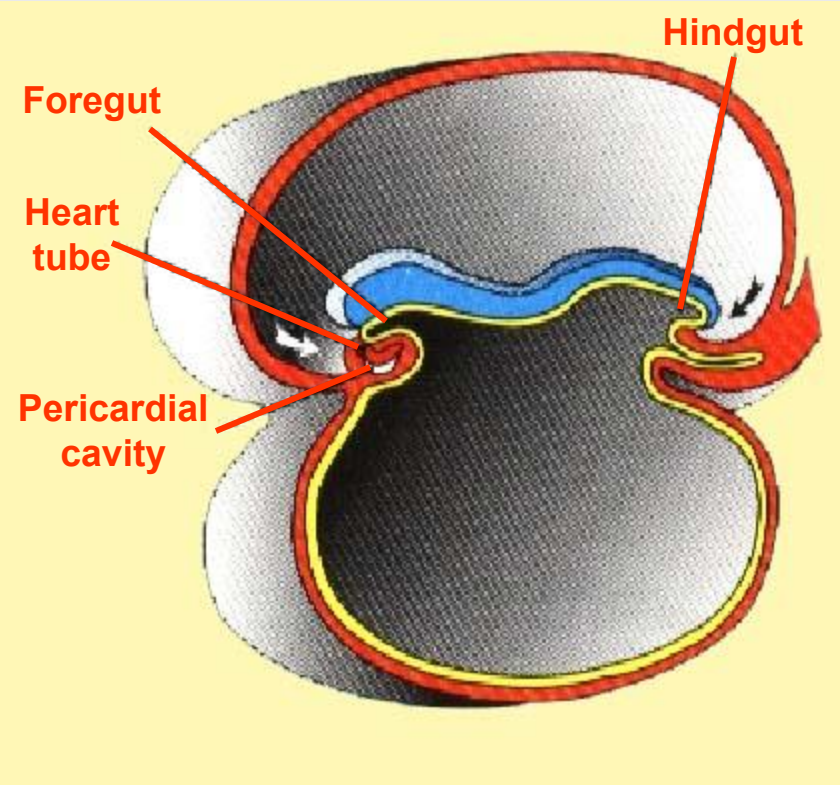
19-day old embryo

Cardiogenic area



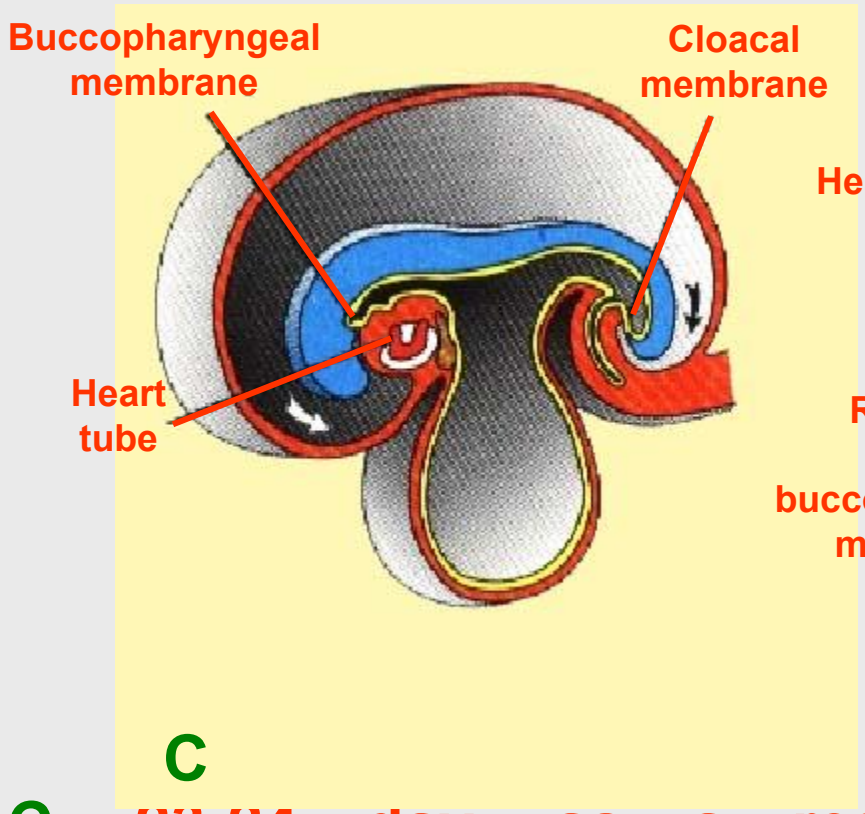
Cephalocaudal section showing the position of the cardiogenic area and pericardial cavity (part of the intraembryonic coelom) in the cranial end of the embryo.

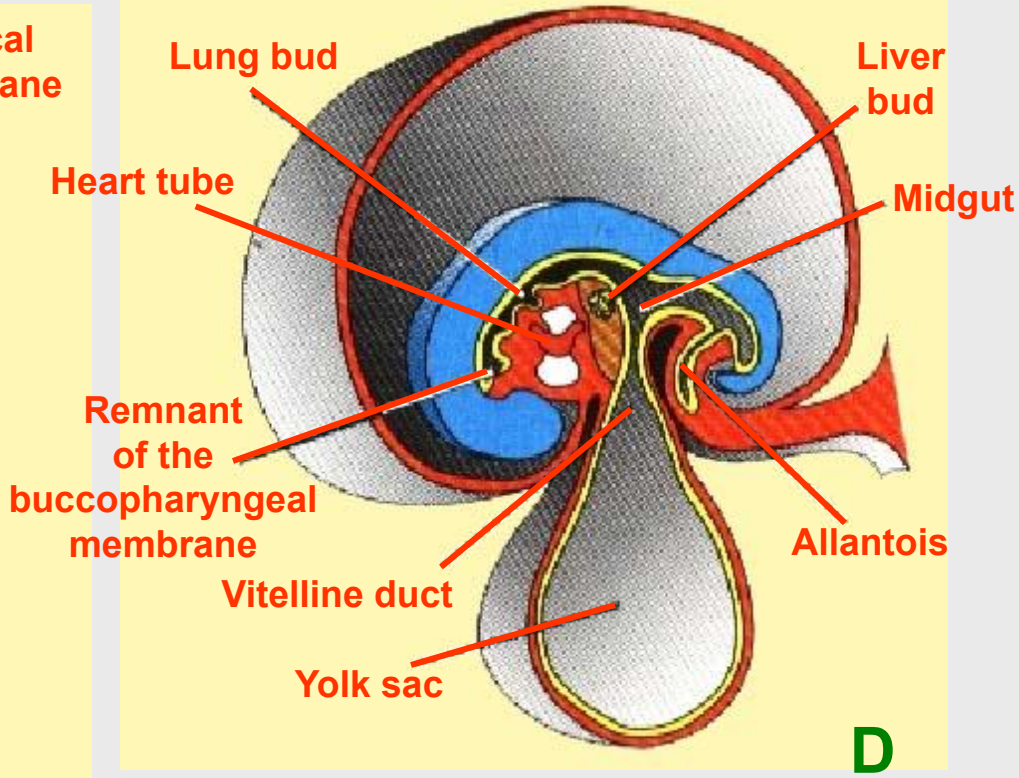
DEVELOPMENT OF THE PRIMITIVE HEART



21-22 day – cephalocaudal folding, formation of the fore-, hind-and midgut. The heart primodium is pulled caudally.

DEVELOPMENT OF THE HEART

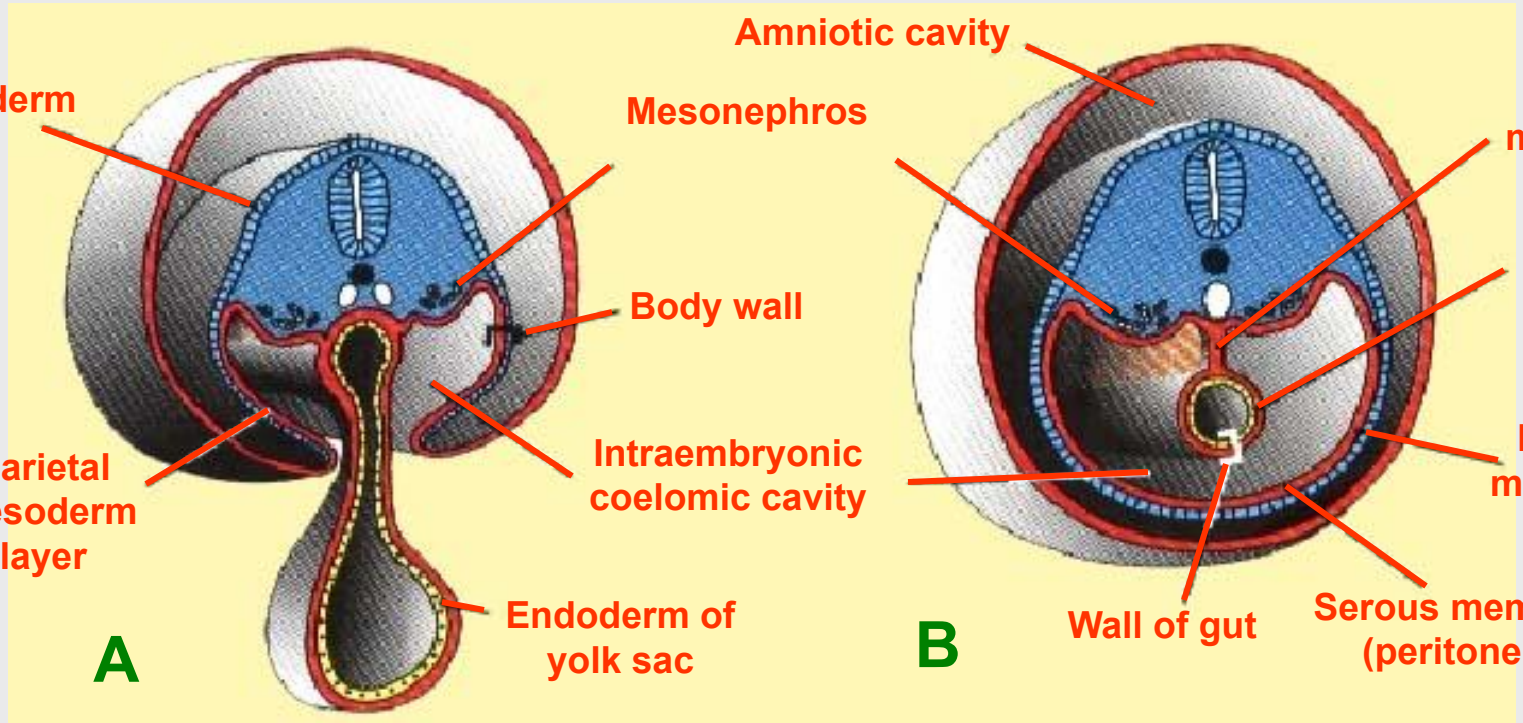




C. 23-24 day, as a result of brain growth and cephalo-caudal folding the prechordal plate (future bucco-pharyngeal membrane) is pulled forward, while primodium of the heart becomes located first in the cervical region,

D. End of the 1st month – and then in the thoracic region.

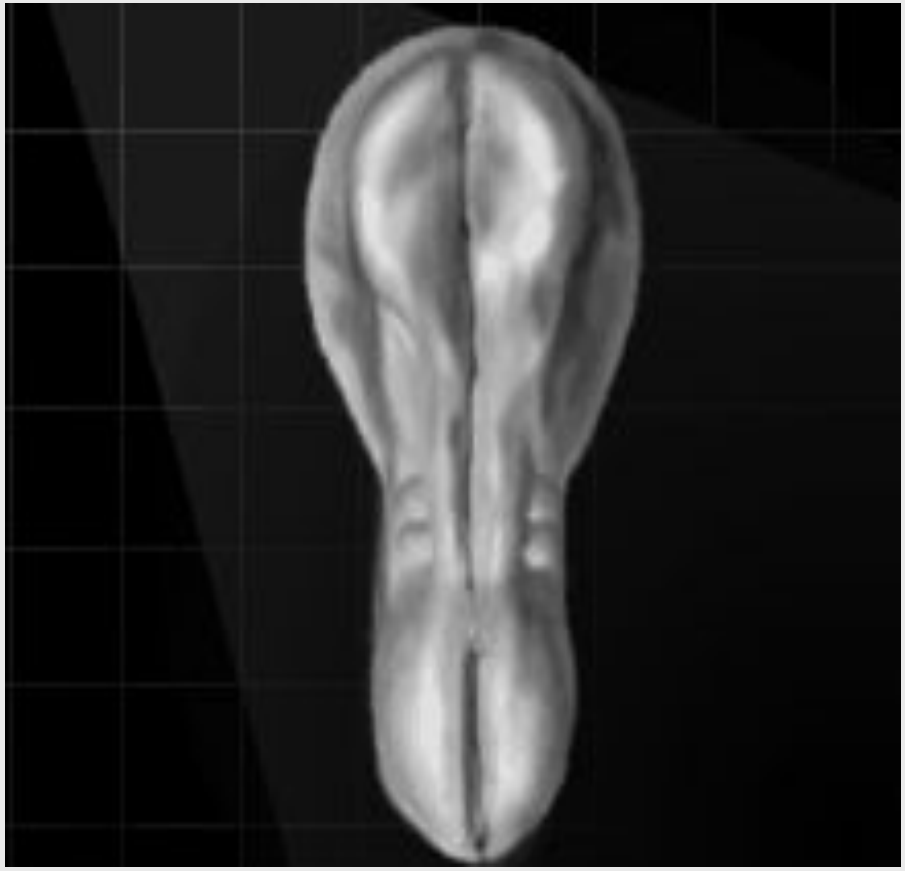
DEVELOPMENT OF THE SEROUS MEMBRANES



B. end of the 4th week, cells of somatic mesoderm lining the intraembryonic coelom, become mesothelial and form parietal layer of the serous membrane (lining the outside of the future peritoneal, pleural and pericardial cavities).

Cells of splanchnic mesodermal layer form the visceral layer of the serous membranes covering the abdominal organs, lungs and heart. Visceral and parietal layers are continuous with each other as the dorsal mesentery, which suspends the gut tube in the peritoneal cavity. Ventral mesentery is a result of thinning of septum transversum.

EARTY DEVELOPMENT OF HEART

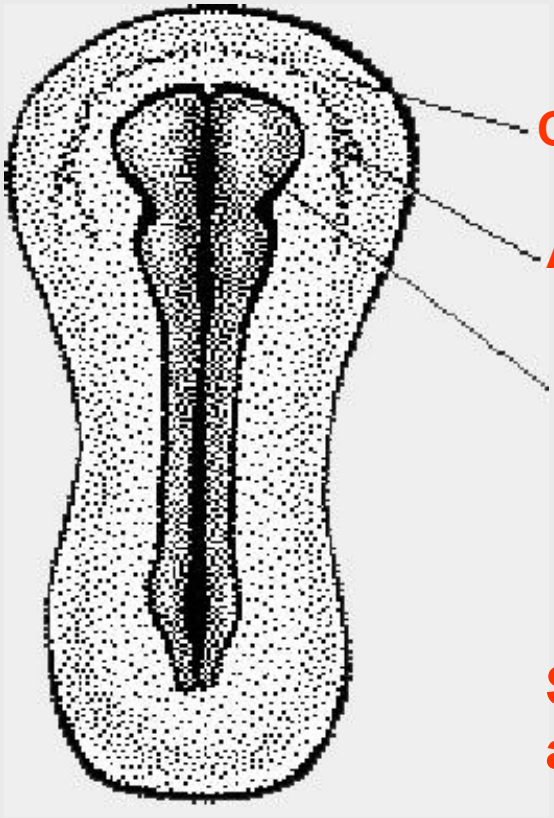


Vascular system appears in the middle of the 3rd week when the embryo is no longer able to satisfy its nutritional require-ments by diffusion alone.

Stage 9
Appearance of Somites
1.5 - 2.5 mm
19 - 21 days post-ovulation
By stage 9, if you could look at the embryo from a top view, it would resemble the sole of a shoe with the head end wider than the tail end, and a slightly narrowed middle.
The first pair of somites appear at the tail and progress to the middle. One to three pairs of somites are present by Stage 9.

Weeks	Days	Somites	Length in mm	Cardiac Events
1-2	0-20	1	1,5	No heart or great vessels
3	20	2	1,5	Cardiogenic plate
3	21	5	1,5	Endocardial tubes
4	22	10	2	Fusion of endocardial tubes
4	23	12	2	Single median cardiac tube, first contraction (ineffective)
4	25	17	2,5	Cardiogenic loop
4	26	20	3	Single atrium
5	29	25	4	Bilobed atrium
5	31	26	4	Beginning of circulation
5	31	28	4,8	Septum primum
5	35		7,5	A-V orifice, 3 chamber heart
6	36		8,5	Septum secundum
6	39		10	Complete inferior septum
6	40		10,5	Septation of bulbus and ventricle
6	42		13	Divided truncus arteriosus
7	49		20	4-chambered heart, Absorption of pulmonary

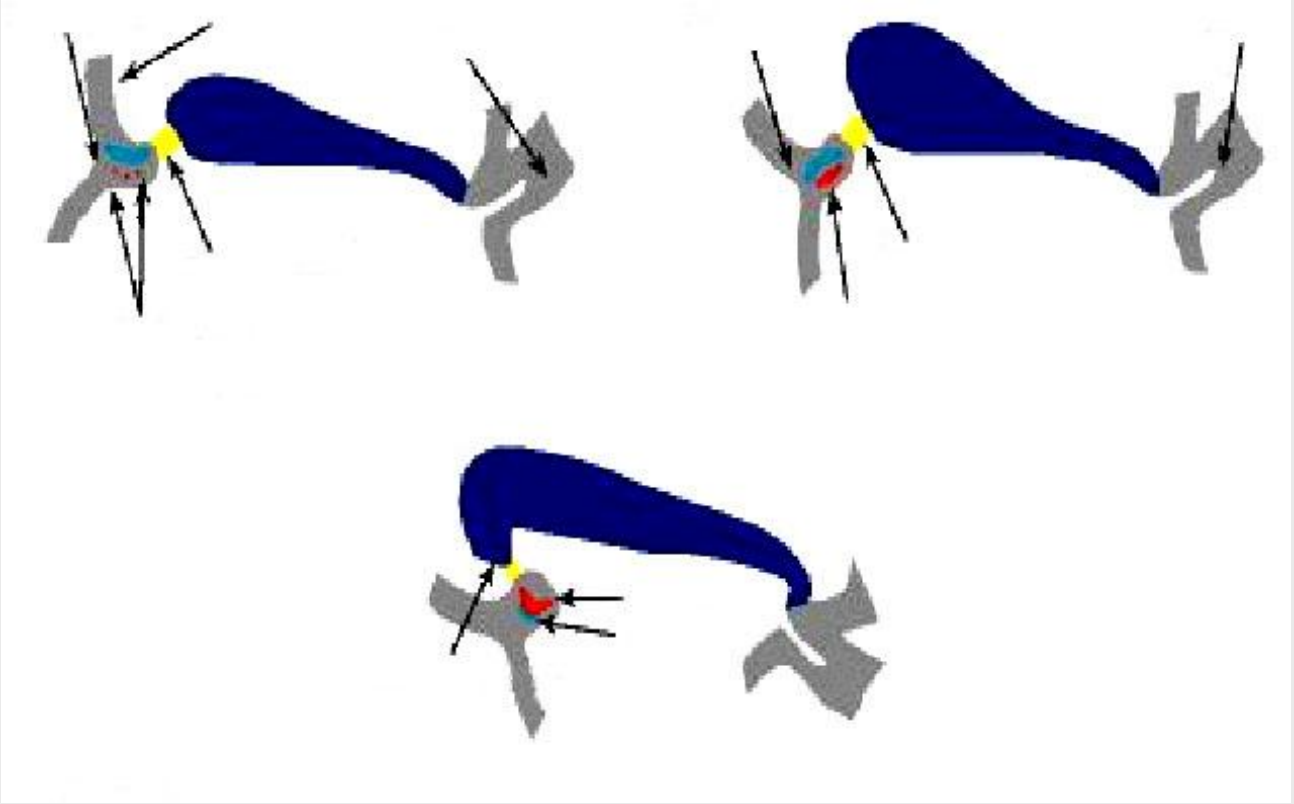
Early Development of the Heart



Superior view of embryo at 16/17

The origins of the heart tube are clusters of angiogenic cells which are located in the cardiogenic plate. The cardiogenic plate, which is derived from splanchnoplueric mesoderm, is located cranial and lateral to the neural plate.

Early Development of the Heart

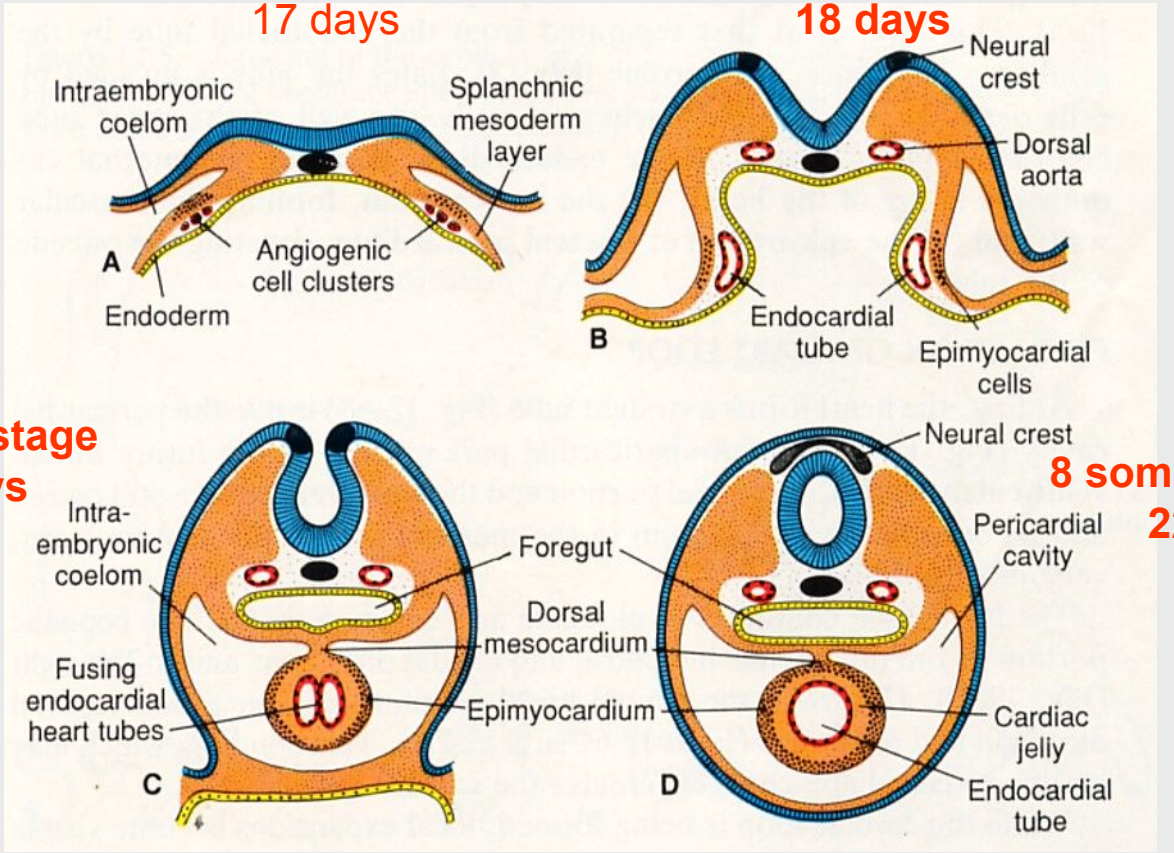


When the neural tube grows it pulls with it the prochordal plate (Oropharyngeal membrane) and the central part of the cardiogenic plate forward causing the central portion of the cardiogenic plate and pericardial portion of the intraembryonic coelomic cavity to move from it's original rostral position to the buccopharyngeal membrane to a ventral and caudal position.

EARLY DEVELOPMENT OF THE HEART

Early presomite embryo – 17 days

Late presomite embryo – 18 days



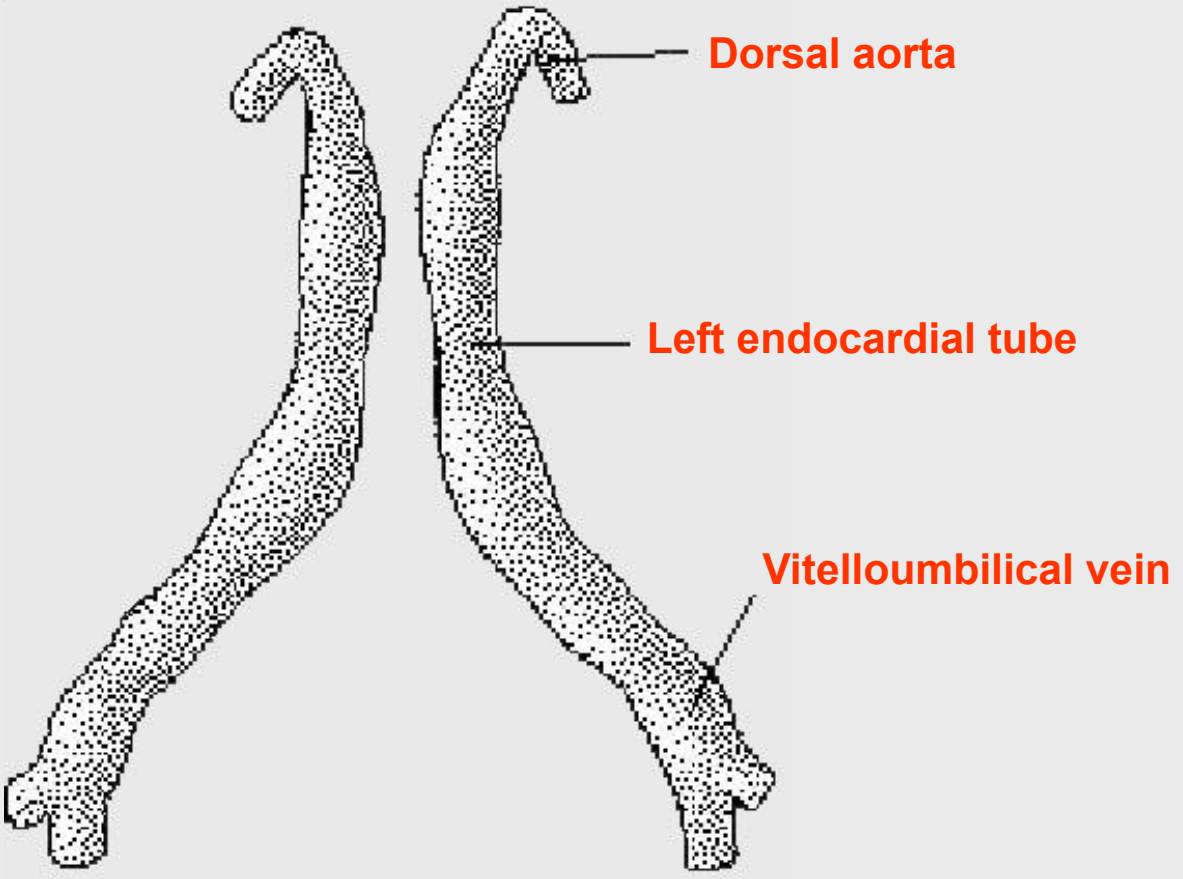
5 somite stage 21 days

8 somite embryo- 22 days

Angiogenic cell clusters which lie in a horse-shoe shape configuration in the plate coalesce to form two endocardial tubes. These tubes are then forced into the thoracic region due to cephalic and lateral foldings where they fuse together forming a single endocardial tube.

Early Development of the Heart

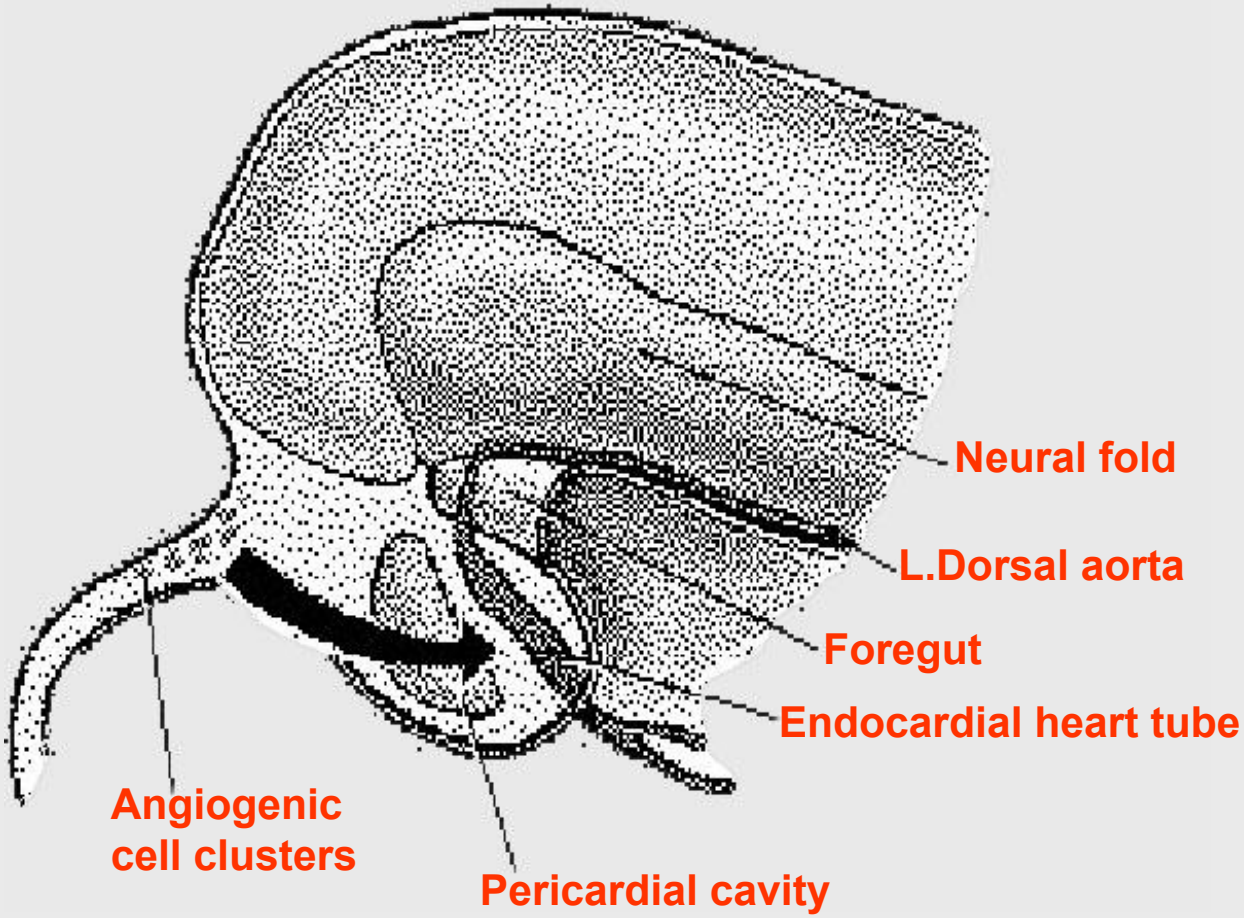
Day 20



These angiogenic cell clusters coalesce to form right and left endocardial tubes.

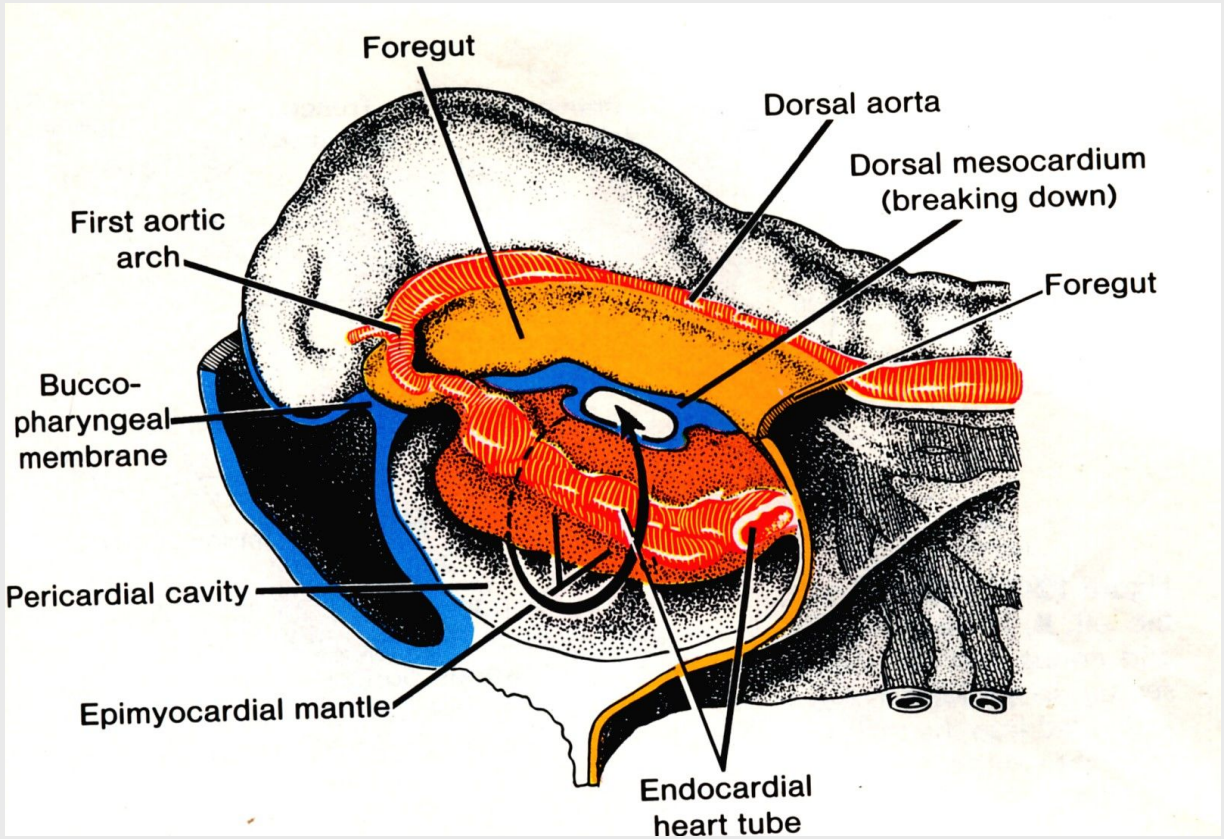
Each tube is continuous cranially with a dorsal aorta, its outflow tract, and caudally with a vitelloumbilical vein, its inflow tract.

Early Development of the Heart



The lateral and cranial folding of the embryo forces the tubes into the thoracic cavity. As a result, these tubes come to lie closer to each other and begin to fuse in a cranial to caudal direction.

Formation of the Myocardium and Epicardium



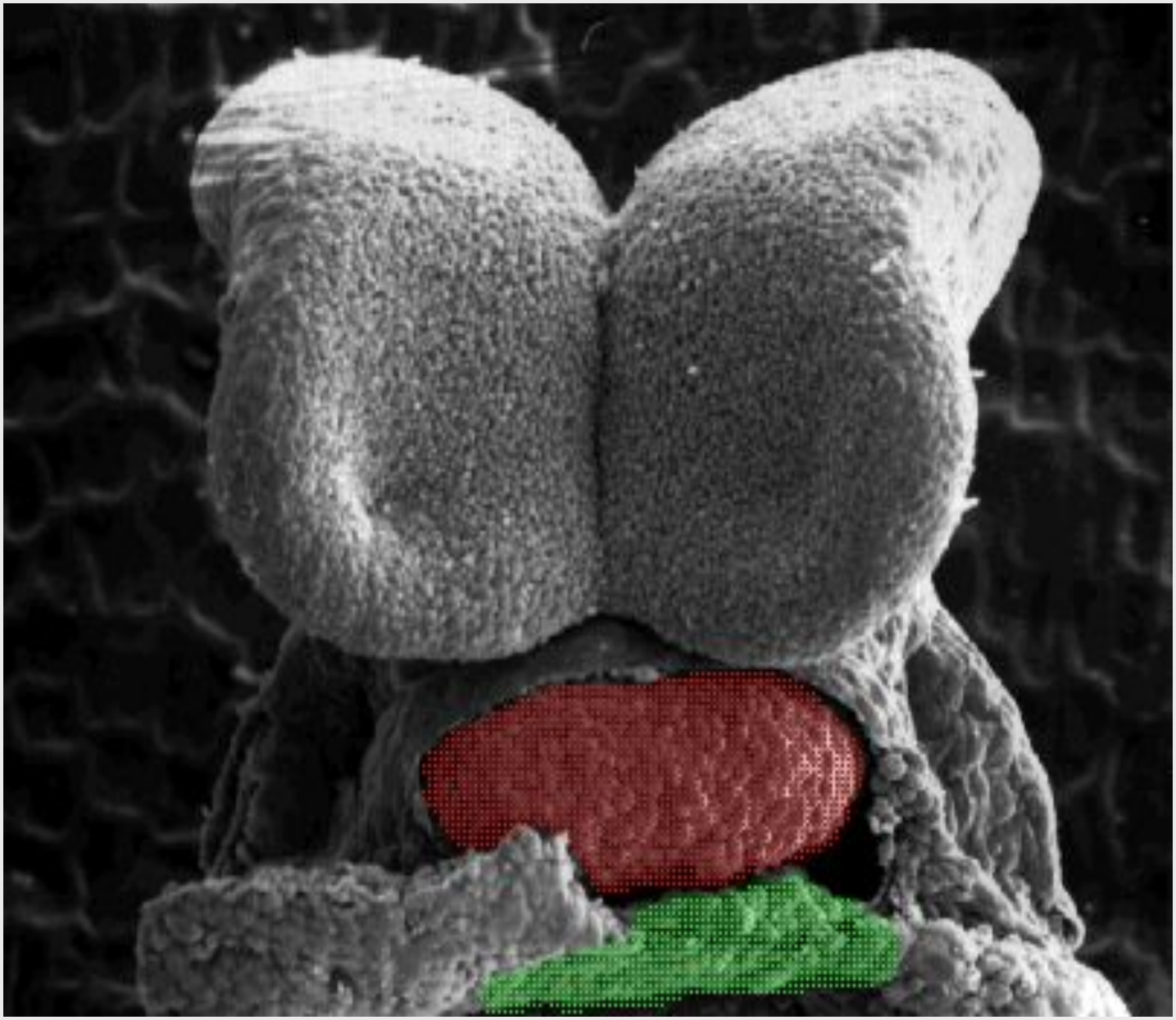
As the single heart tube is being formed the mesoderm around it thickens to form the myoepicardial mantle, this is at first separated from the endothelial tube by the cardiac jelly, which later is invaded by mesenchymal cells. The endothelial layer forms the endocardium and the myoepicardial mantle gives rise to the myocardium and the visceral pericardium (epicardium).

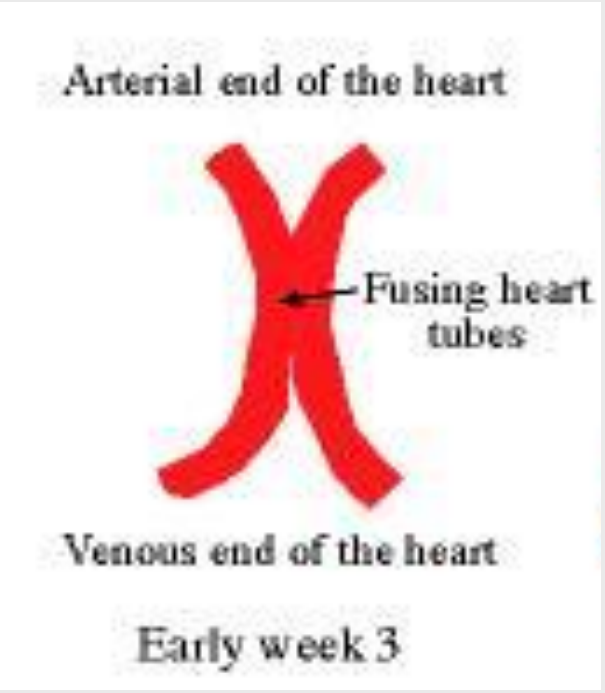
Early Heart Development, SEM

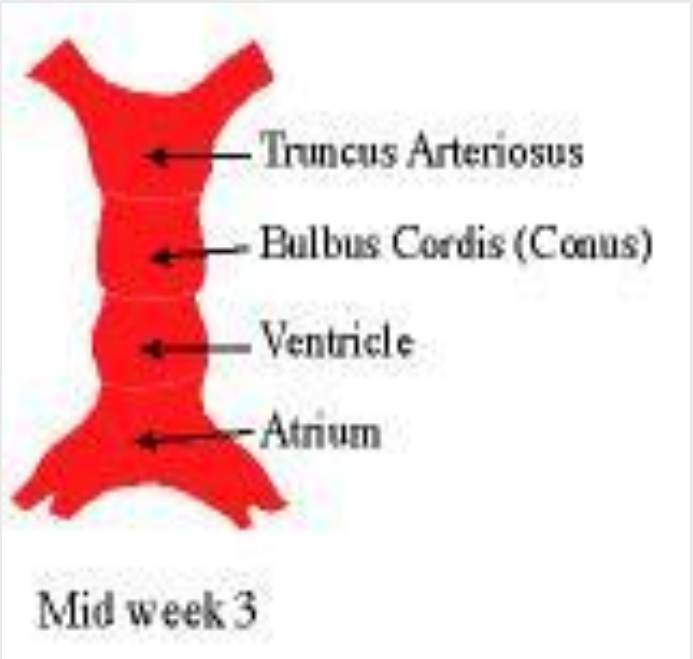
Central veiw of fusing endocardial tubes within pericardial cavity

At approximately day 21 the endocardial tubes are completely fused.

The heart starts to beat at day 22, but the circulation does not start until days 27 to 29.





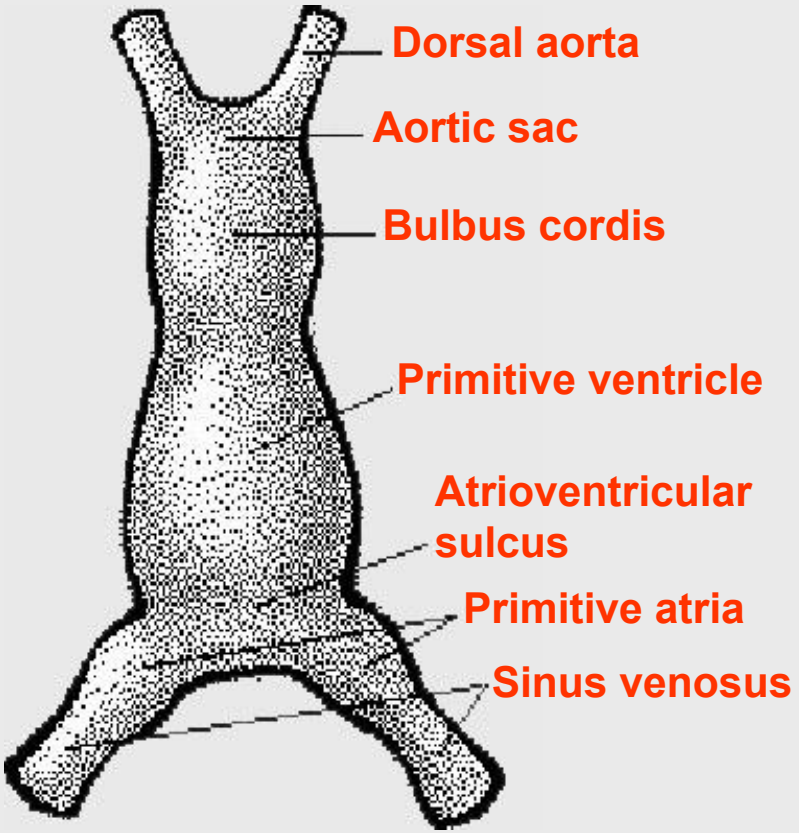


The single tubular heart develops many constrictions outlining future structures. The cranial most area is the bulbus cordis which extends cranially into the truncus arteriosus, which in turn is connected to the aortic sac and through the aortic arches to the dorsal aorta. The primitive ventricle is caudal to the bulbus cordis and the primitive atrium is the caudal most structure of the tubular heart. The atrium which is paired connects to the sinus venosus which receives the viteline (from yolk sac), common cardinal (from embryo) and umbilical (from primitive placenta) veins. The primitive atrium and sinus venosus lay outside the caudal end of the pericardial sac, and the truncus arteriosus is outside the cranial end of the pericardial sac.

Early Development of the Heart

The newly formed heart tube may be divided into regions. Starting caudally:

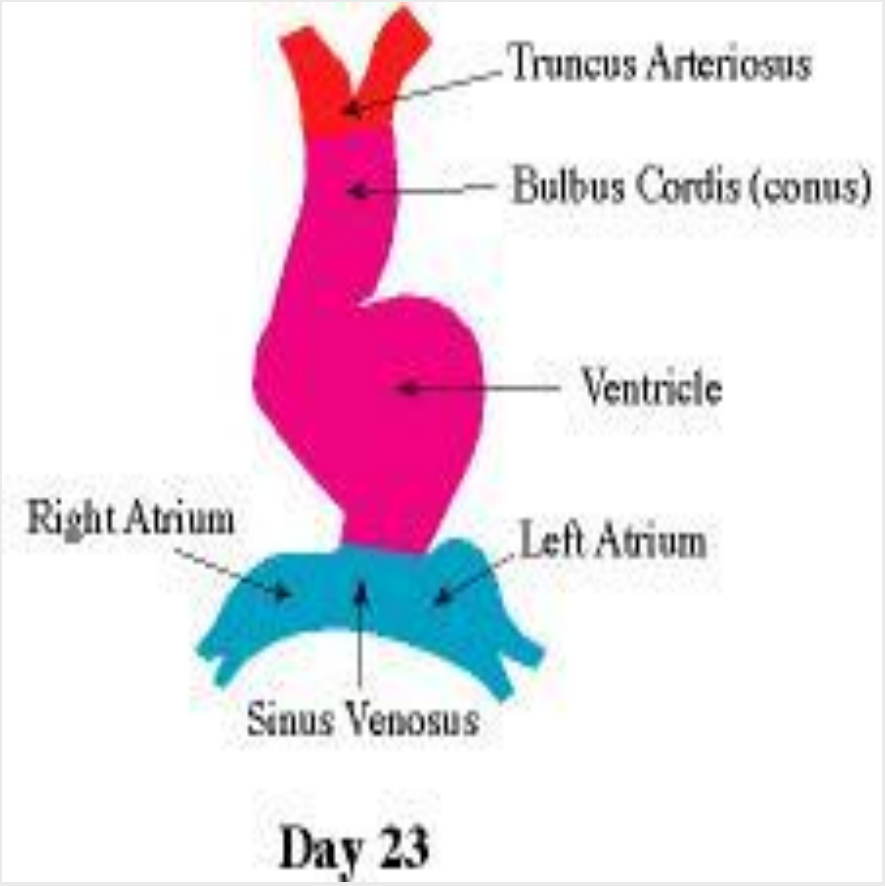
- sinus venosus - consisting of right and left horns,
- paired primitive atria. These structures will later fuse together to form common atrium,
- atrioventricular sulcus divides the atria and the primitive ventricle.
- primitive ventricle expands to become the left ventricle.
- interventricular sulcus divides the primitive ventricle and the bulbus cordis,
- bulbus cordis which may be divided as follows:
  1. conus cordis
  2. truncus arteriosus aortic sac.
  3. bulbus cordis - the proximal portion forms the right ventricle



Early Heart Development

WEEK	DAY	LENGTH	EVENT
III	16/17		Angiogenic cell clusters lie in cardiogenic plate
	18-20		Endocardial tubes are formed and begin to move towards each other
	2 somites	1,8 mm	Endocardial tubes begin to fuse to form a single heart tube The heart tube is forced into the thoracic region due to cephalic and lateral flexions

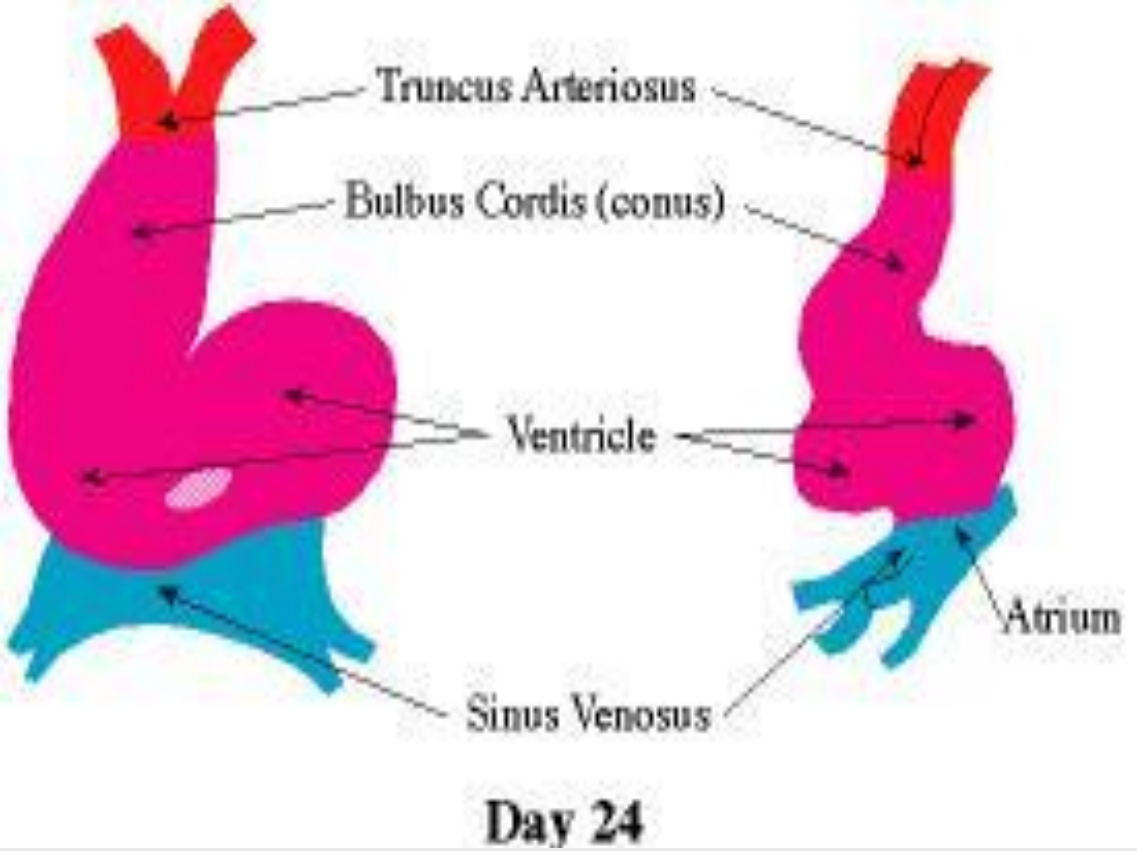
Early Development of the Heart



The original paired cardiac tubes fuse, with the "ventricular" primordia initially lying above the "atria".

Growth of the cardiac tube flexes it into an "S-shape" tube, rotating the "ventricles“.

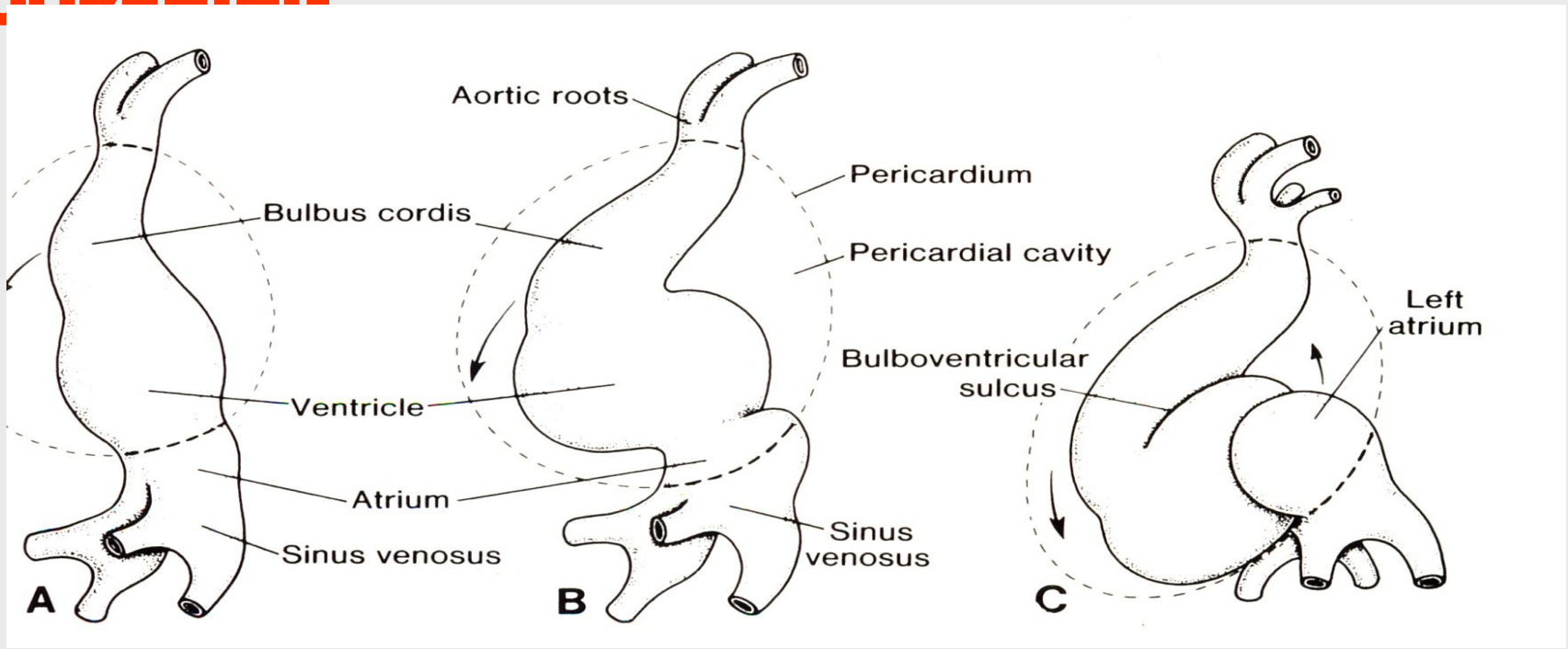
Early Development of the Heart



The bulboventricular portion of the heart grow faster than the pericardial sac and the rest of the embryo. Since the bulboventricular portion is fixed at the cranial end by the aortic arch arteries and at it's caudal end by the septum transversum, the bulboiventricular portion will fold as it elongates.

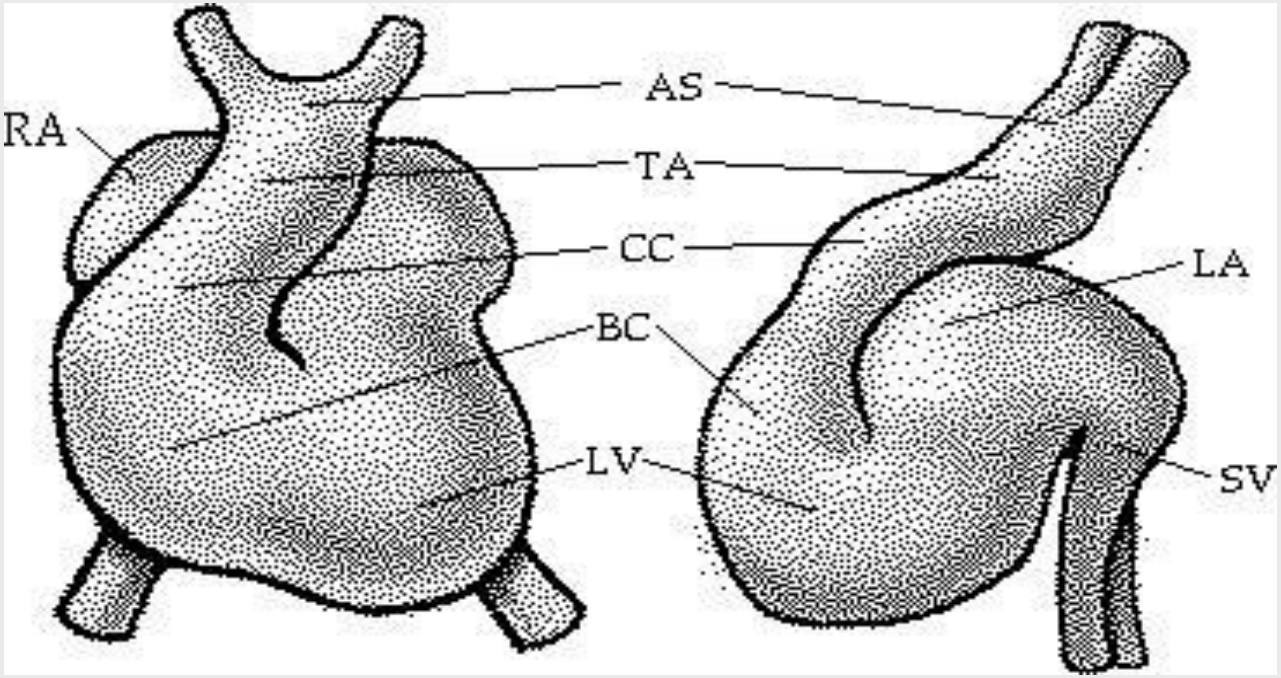
The cephalic end of the heart tube will bend ventrally, caudally and slightly to the right.

LOOPENING



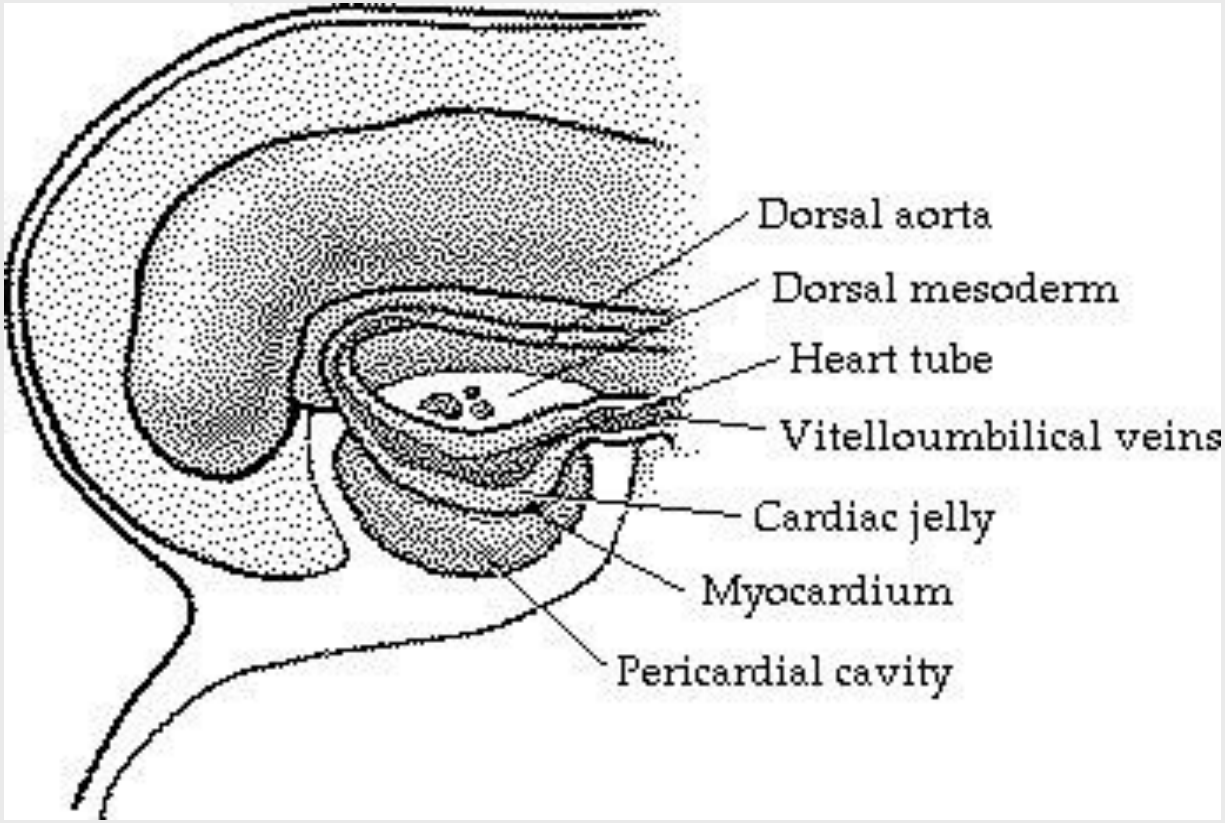
The bulboventricular sulcus will become visible from the outside, and from the inside there will be a primitive interventricular foramen. The internal fold formed by the bulboventricular sulcus is known as the bulboventricular fold. The bulboventricular segment of the heart is now U-shaped, bulbus cordis occupies the right arm of the U-shape and the primitive ventricle occupy the left arm of the U-shaped bulbo-ventricular segment. The looping of the bulboventricular segment of the heart will cause the atrium and sinus venosus to become dorsal to the heart loop.

LOOPENING



By the time the heart tube has formed the bulboventricular loop, the two primitive right and left atria have fused to form a common atrium. Note that it now lies cranial to the primitive ventricle and dorsal to the bulbus cordis. The truncus arteriosus lies on the roof of the common atrium causing a depression and indicates where septation of the atrium will occur. AS = Aortic sac, BC = Bulbus cordis, CC = Conus cordis, LA = Left atrium, LV = Left ventricle, RA = Right atrium

- SV = Sinus venosus, TA = Truncus arteriosus.



The newly formed heart tube bulges into the pericardial cavity and is attached to the dorsal wall by a fold of tissue, the dorsal mesoderm. This is a derivative of foregut splanchnoplueric mesoderm. Eventually this will rupture leaving the heart tube suspended in the pericardial cavity anchored cranially by the dorsal aortae and caudally by the vitelloumbilical veins.

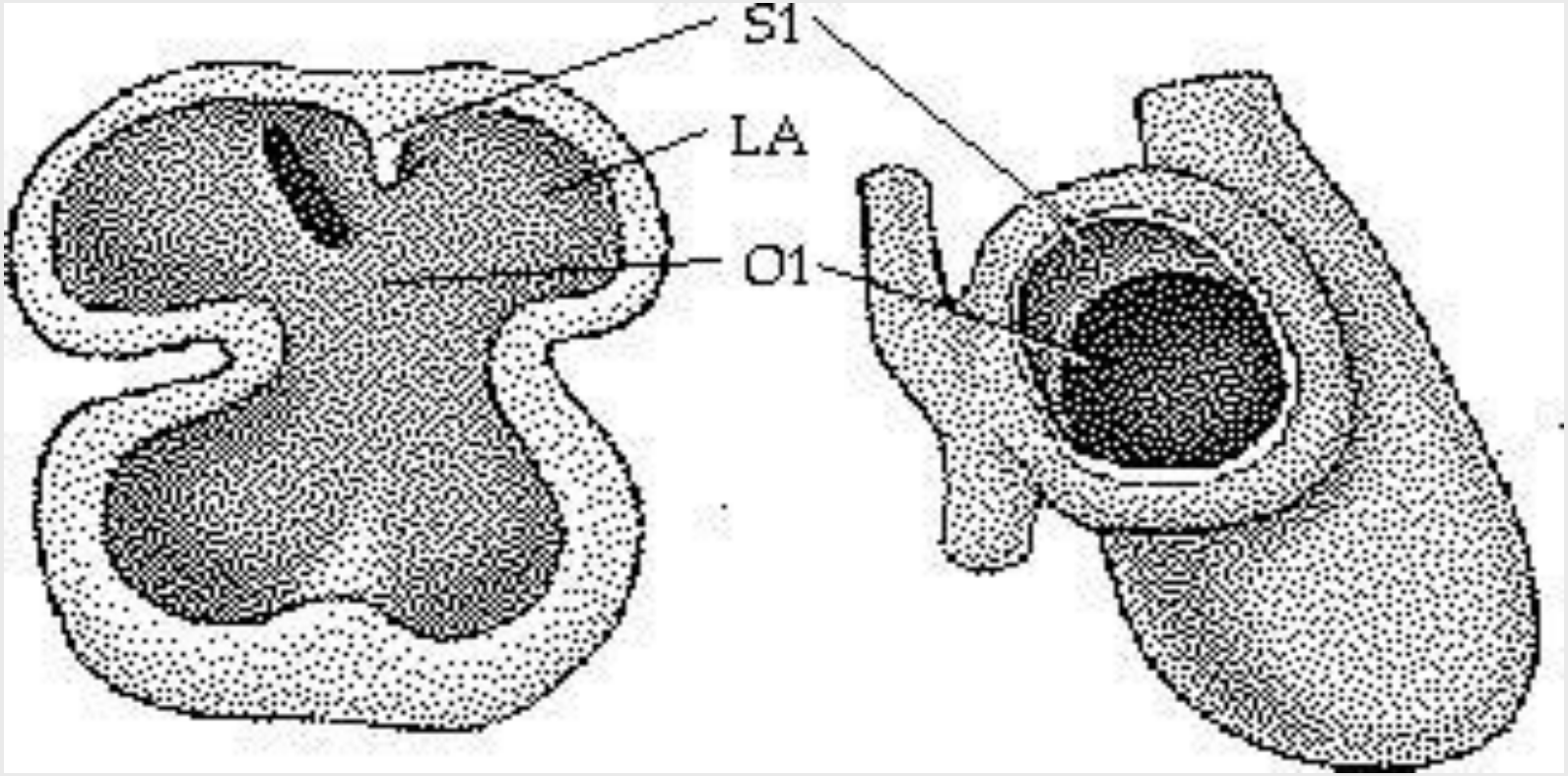
As it bulges into the cavity it becomes invested in a layer of myocardium. A layer of acellular matrix, the cardiac jelly, separates the myocardium and the endothelial heart tube.

The primitive heart tube can be subdivided into primordial heart chambers starting caudally at the inflow end: the sinus venosus, primitive atria, ventricle, and bulbus cordis (conus).

Early Development of the Heart

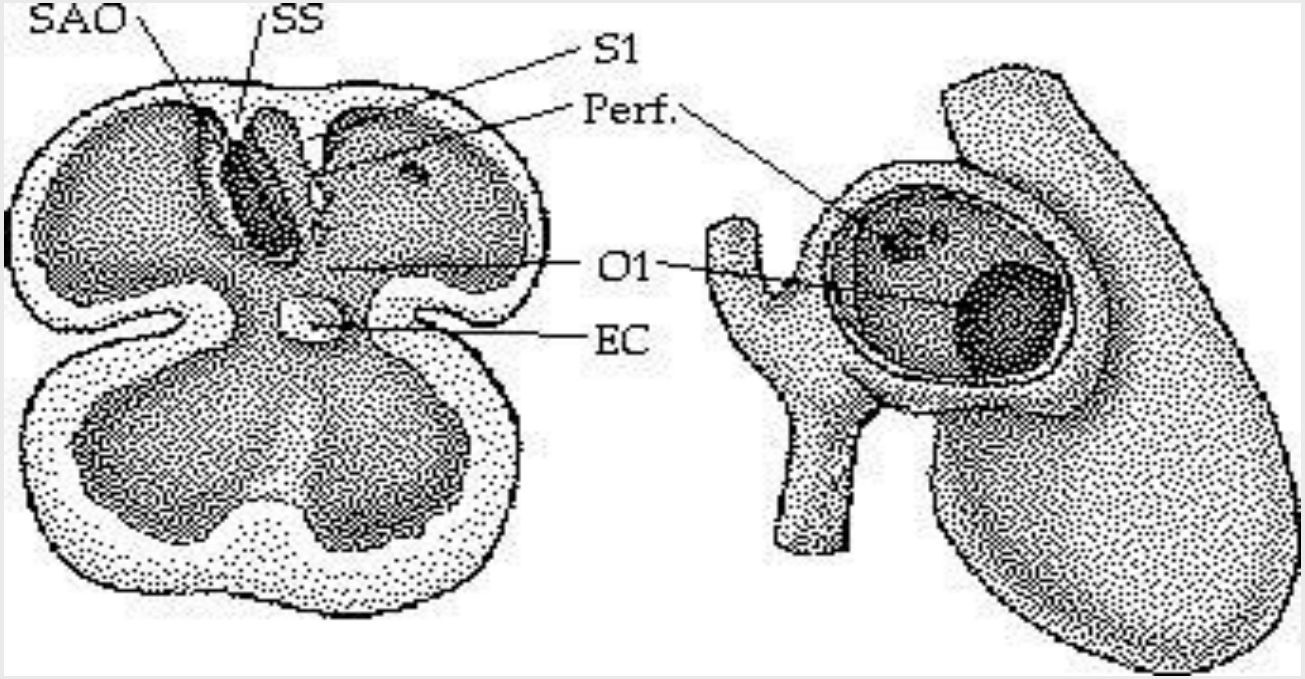
WEEK	DAY	LENGTH	EVENT
IV	22	2,0 mm 4 somites	Endocardial heart tubes have completely fused to form a single heart tube. The heart begins to beat. Splanchnopleuric mesoderm invests the heart tube and forms the pericardial cavity.
	23	2,2-2,5 mm 7/8 som.	The heart tube begins to grow rapidly, forcing it to fold upon itself.
	24	14 somites	The centrally located sinoatrial junction begins to shift to the right. Perforations appear in the dorsal mesocardium.
	25-28	3,2-5 mm	The bulboventricular loop is formed. Septum primum appears.
	28	5 mm 16 somites	The ventricular septum appears as a small ridge on the floor of the common ventricle. The ventricules begin to dilate. A single pulmonary artery grows from the outer dorsal wall of the left atrium. The endocardial cushions appear.

ATRIAL PARTITIONING



The partitioning of the atrium begins with the appearance of *septum primum* at about the 28th day. This is a crest of tissue that grows from the dorsal wall of the atrium towards the endocardial cushions - the ostium (opening) formed by the free edge of septum primum is the *ostium primum*.

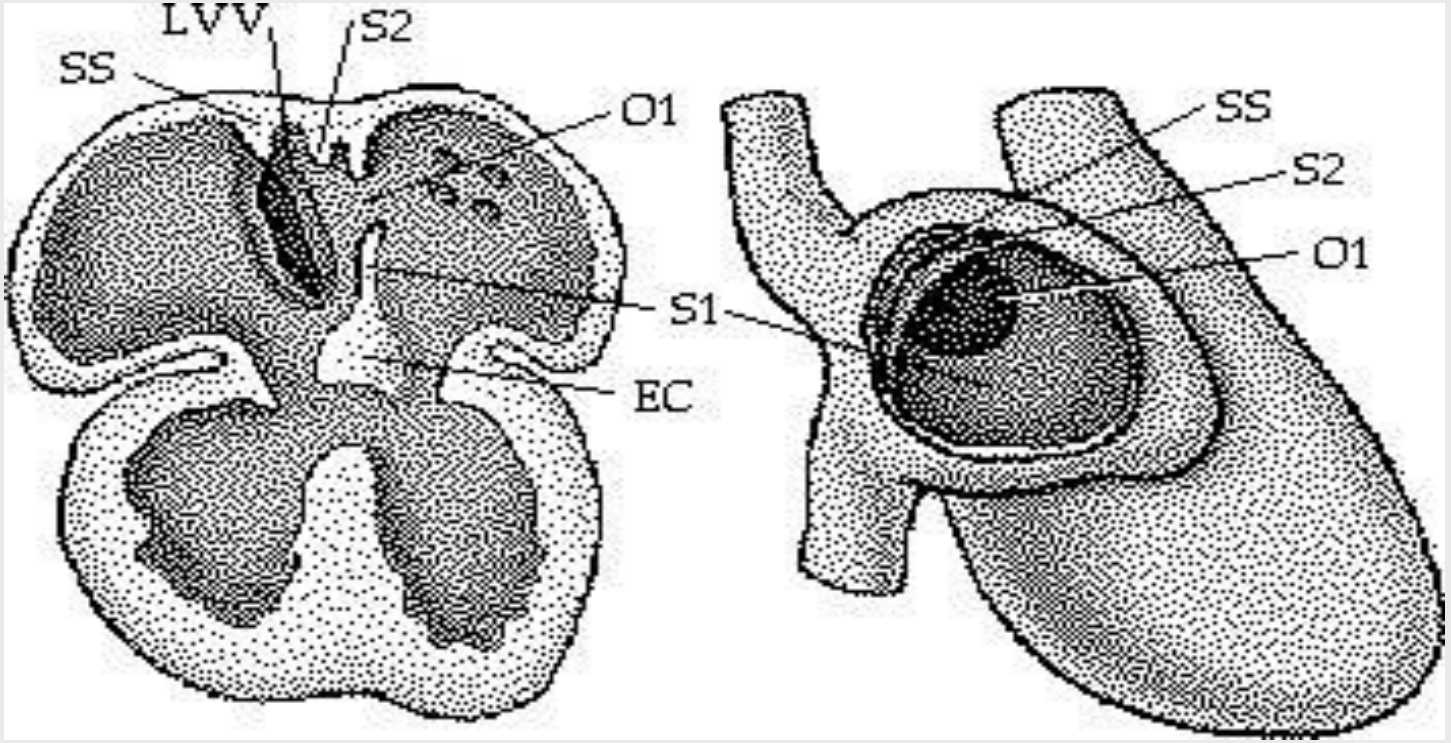
ATRIAL PARTITIONING



Before the septum primum fuses with the endocardial cushions, perforations appear in the upper portion of the septum primum. These perforations will coalesce to form the ostium secundum.

- **SAO = Sinoatrial orifice**
- **SS = Septum spurium**
- **S1 = Septum primum**
- **Perf = Perforations**
- **O1 = Ostium secundum**
- **EC = Endocardial cushions**

ATRIAL PARTITIONING

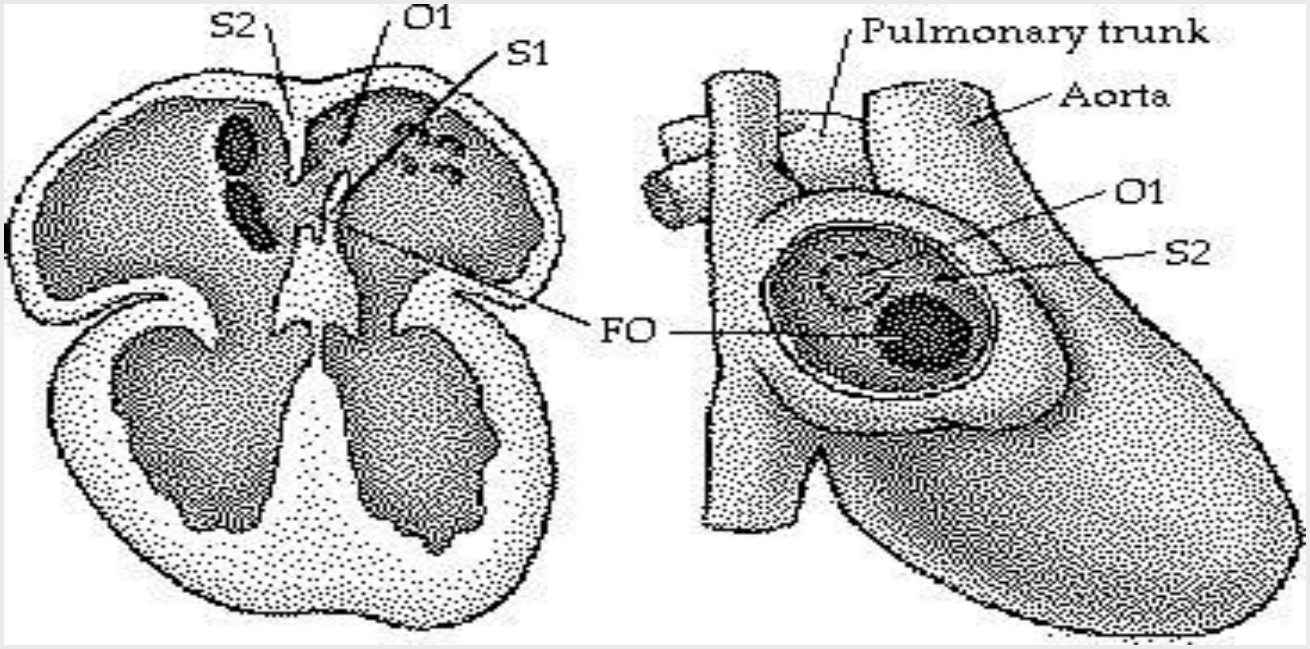


Unlike the septum primum, septum secundum does not fuse with the endocardial cushions. Its free edge forms the foramen ovale. The left venous valve and the septum spurium located on the dorsal wall of the right atrium, fuse with the septum secundum as it grows.

EC = Endocardial cushions, LVV = Left venous valve, O1 = Ostium secundum, SS = Septum spurium, S1 = Septum primum, S2 = Septum secundum.

ATRIAL PARTITIONING

FO - foramen ovale



At the end of the 7th week the human heart has reached its final stage of development. Because the fetus does not use its lungs, most of the blood is diverted to the systemic circulation. This is accomplished by a right to left shunting of blood that occurs between the two atria.

The foramen ovale and the septum primum control this right and left communication. The septum primum acts as a valve over the foramen ovale. At birth the child will use its lungs for the first time and consequently more blood will flow into the pulmonary circulation. The pressure increase in the left atrium (where the pulmonary veins empty) will force septum primum to be pushed up against septum secundum. Shortly thereafter the two septa fuse to form a common atrial septum.

DEVELOPMENT OF THE HEART

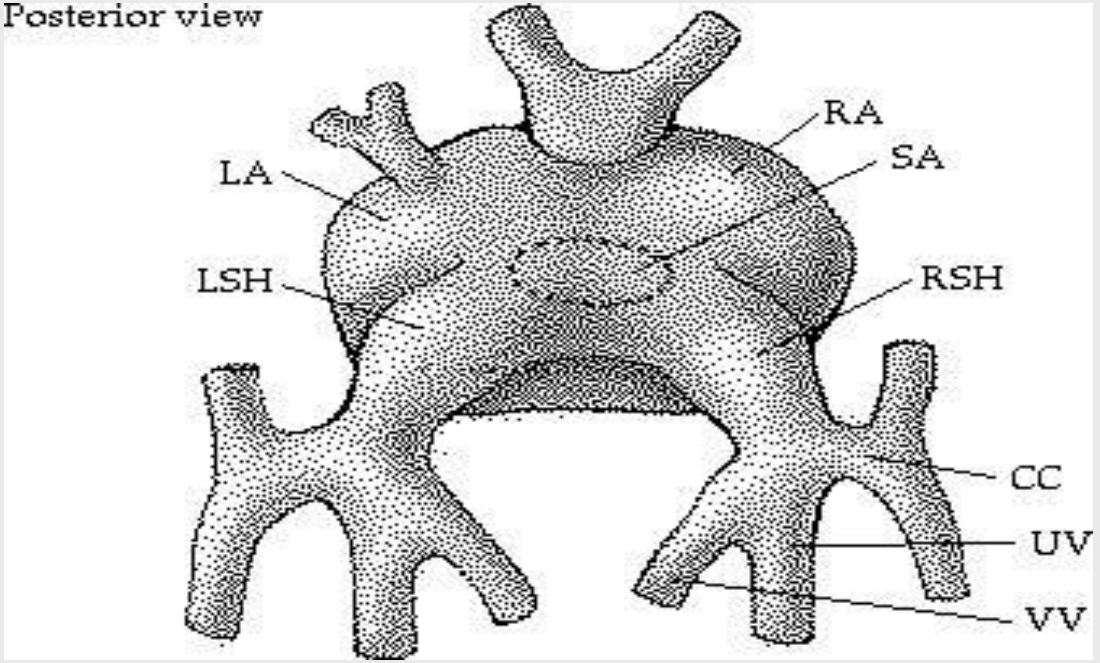
WEEK	DAY	LENGTH	EVENT
V	29	6-7 mm	Truncal swellings appear
	30/31		Perforations appear in septum primum appear
	32/33	9 mm	The bulboventricular flange begins to recede The atrioventricular canal gains a “dog’s bone” appearance The ostium secundum is formed by the free edge of septum primum
	35		The sinoatrial junction has shifted completely to the right
VI	37	14 mm	The septum secundum ceases to grow; its free edge forms the foramen ovale.
	42		Superior and inferior endocardial cushions fuse.

Early Development of the Heart

WEEK	DAY	LENGTH	EVENT
VII	46		The ventricular septum ceases to grow. The coronary sinus is formed.
	end of 7th week		The interventricular canal is completely obliterated.
VIII	early In wk		The outflow tracts (the aorta and the pulmonary trunk) are completely separated.

Fate of the Sinus Venosus (Formation of the Right Atrium)

- VV = Vitelline vein
- UV = Umbilical vein
- CC = Common cardinal vein
- SA = Sinoatrial orifice
- RSH, LSH = right, left sinus horn
- RA, LA = right, left atrium



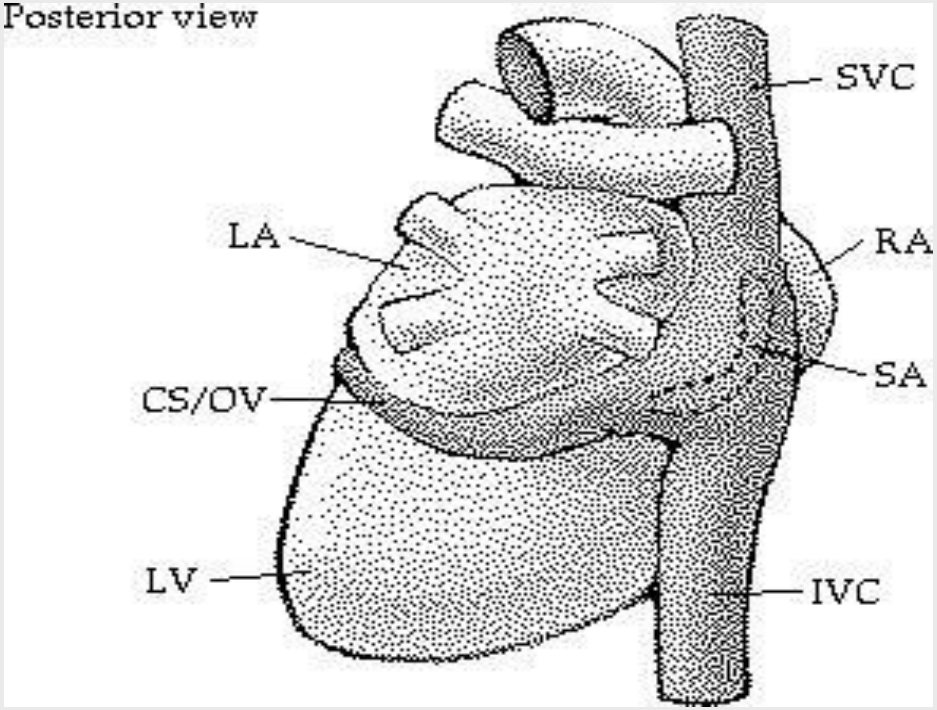
Unlike the atria, the sinus vinosus remains a paired structure with right and left horns. Each horn receives venous blood from three vessels:

1. Vitelline vein
2. Umbilical vein
3. Commom cardinal vein

Communication between the sinus venosus and the primitive atrium, the sinoatrial orifice, is centrally located.

DEVELOPMENT OF THE ATRIA

- SVC = Superior vena cava
- IVC = Inferior vena cava
- SA = Sinoatrial junction
- CS/OV = Coronary sinus/ oblique vein of left ventricle
- LA, RA = Left, right atrium
- LV, RV = Left, right ventricle



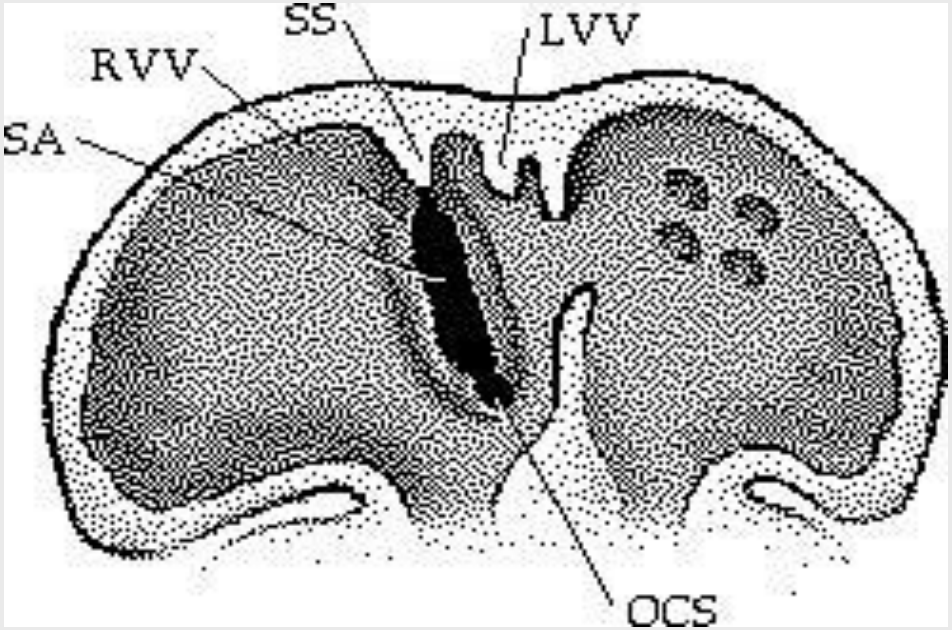
Gradually the sinoatrial oriface shifts to the right, due to the shunting of blood to the right, until the sinus venosus communicates with only the right atrium. The fate of each structure is as follows:

- the right sinus horn becomes enlarged
- the right anterior cardinal vein becomes the superior vena cava
- the right vitelline vein becomes the inferior vena cava
- the right umbilical vein is obliterated

Conversely, the left vein counterparts are obliterated and the left sinus horn diminishes in size and forms the *coronary sinus and the oblique vein of the left ventricle.*

SEPTATION

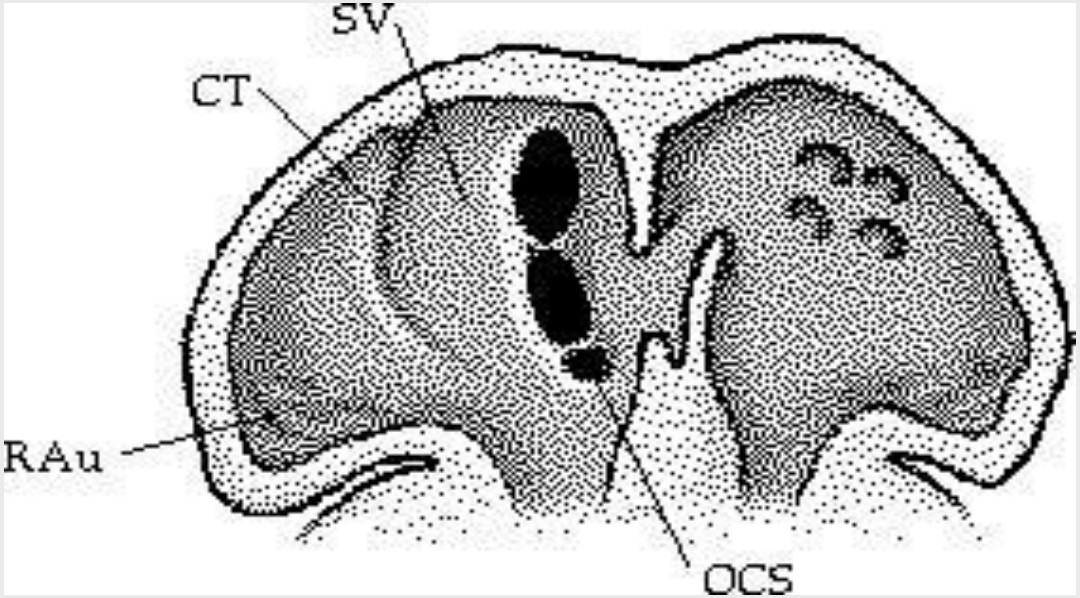
- LVV, RVV = left, right venous valve
- SS = Septum spurium
- SA = Sinoatrial oriface
- OCS = orifice of the coronary sinus



Internally, the sinoatrial orifice is flanked by two valves, the right and left venous valves. Superiorly these two valves meet to form the *septum spurium.* Note that the left horn opens up underneath the orifice of the right horn (sinoatrial oriface). This is the *orifice of the coronary sinus.*

Formation of the Right Auricle

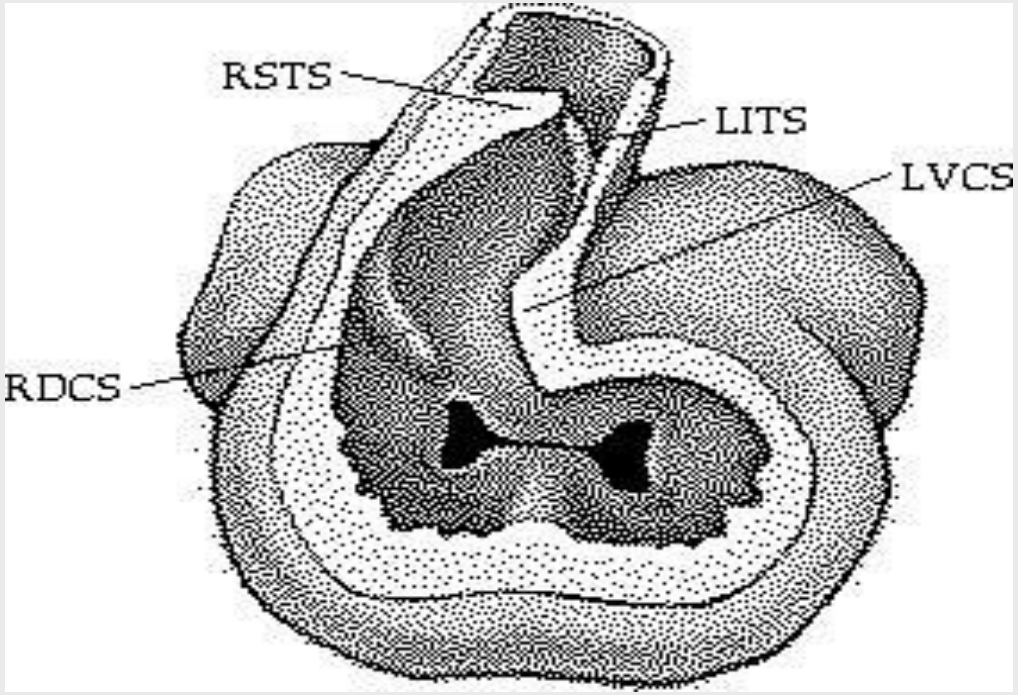
- RAu = Right auricle
- SV = Sinus venarum
- CT = Crista terminalis
- OCS = Orifice of the coronary sinus



Further into development the right sinus horn is incorporated into the expanding right atium. As the atrium expands the smooth tissue of the sinus venosus displaces the trabeculated tissue of the primitive right atrium anteriorly and laterally where it becomes the adult *right auricle.* The smooth tissue forms part of the atrium called the *sinus venarum*. *Crista Terminalis*, a ridge of tissue located to the right of the sinoatrial orifice, forms the boundary between the auricle and the sinus venarum.

Formation of the Aorta and Pulmonary Tract

- **RSTS/ LITS** = Right superior/ Left inferior truncal swelling,
- **RDCS/ LVCS** = Right dorsal/ Left ventral conus swelling



The final morphological change in the heart is the partitioning of the outflow tract - - the truncus arteriosus and the conus cordis - - into the aorta and the pulmonary trunk. This is accomplished by the development of a septum that forms in the outflow tract and the emergence of the two great vessels.

The septum forms from two pairs of swellings which grow from the walls of the outflow tract. These are the ***truncus swellings*** and the ***conus swellings***.

Formation of the Aorta and Pulmonary Tract

- **RSTS/ LITS = Right superior/ Left inferior truncal swelling,**
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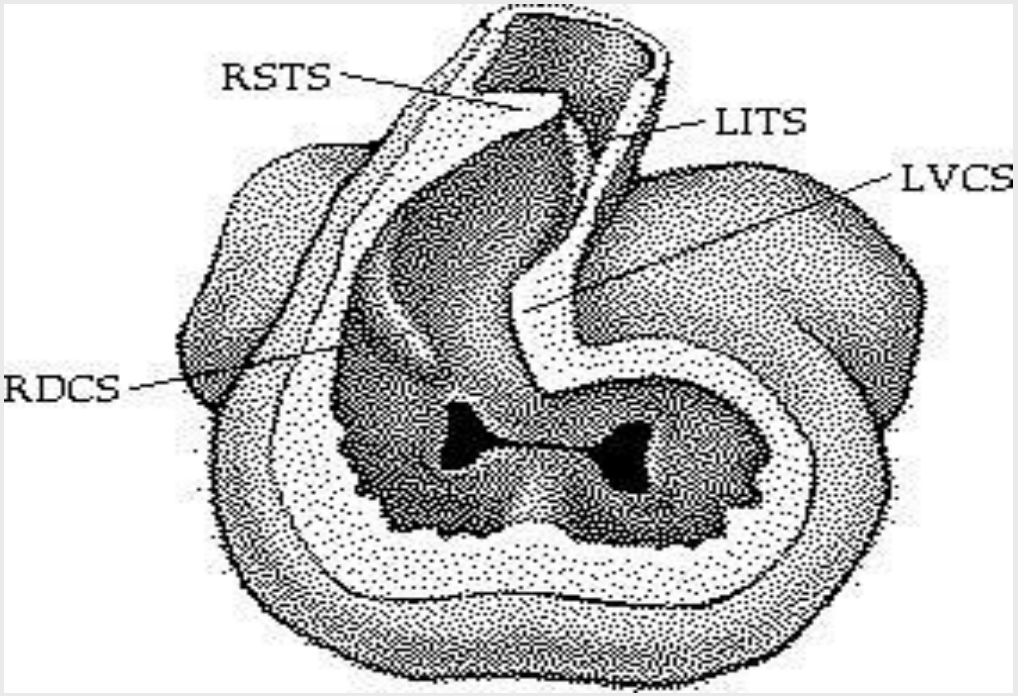
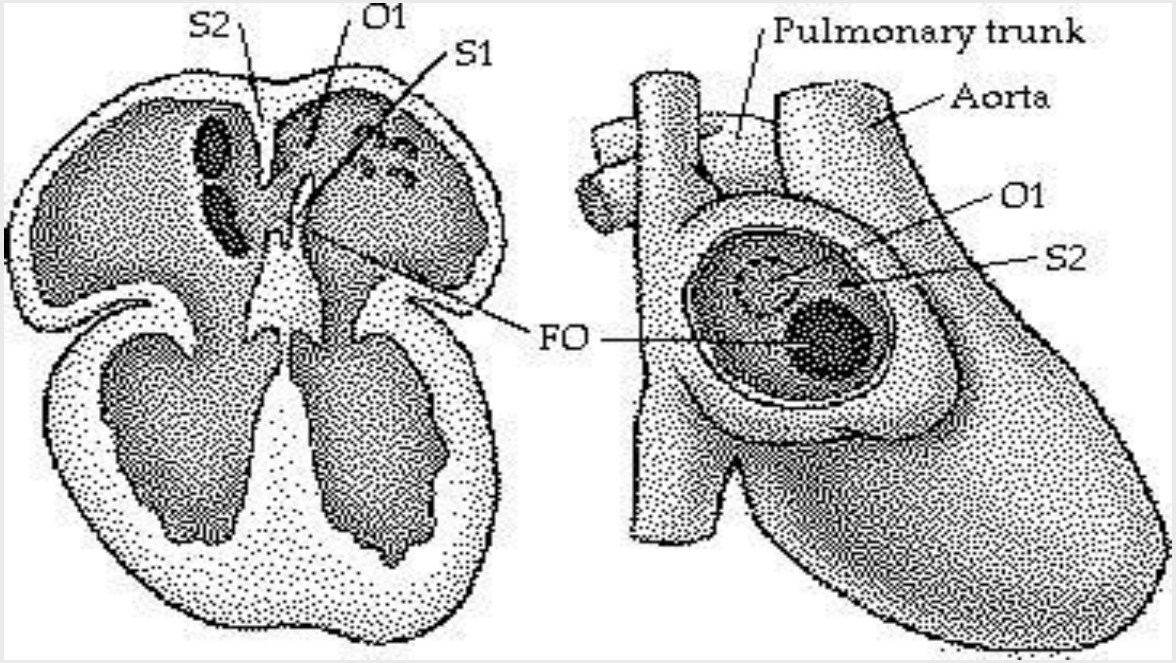


Truncal swellings: *Right superior* which grows distally and to the left. *Left inferior* which grows distally and to the right. Both develop at the proximal part of the truncus and proceed to grow in two directions; 1) distally towards the aortic sac and 2) into the lumen of the outflow tract where they will eventually fuse together.

Conus swellings: *Right dorsal* which is continuous with the right superior *Left ventral* which is continuous with the left inferior Like the truncal swellings, the conal swellings grow distally and towards each other, however they appear after the first pair. These conus swellings eventually fuse with the truncal swellings.

Pulmonary Veins (Formation of the Left Atrium)

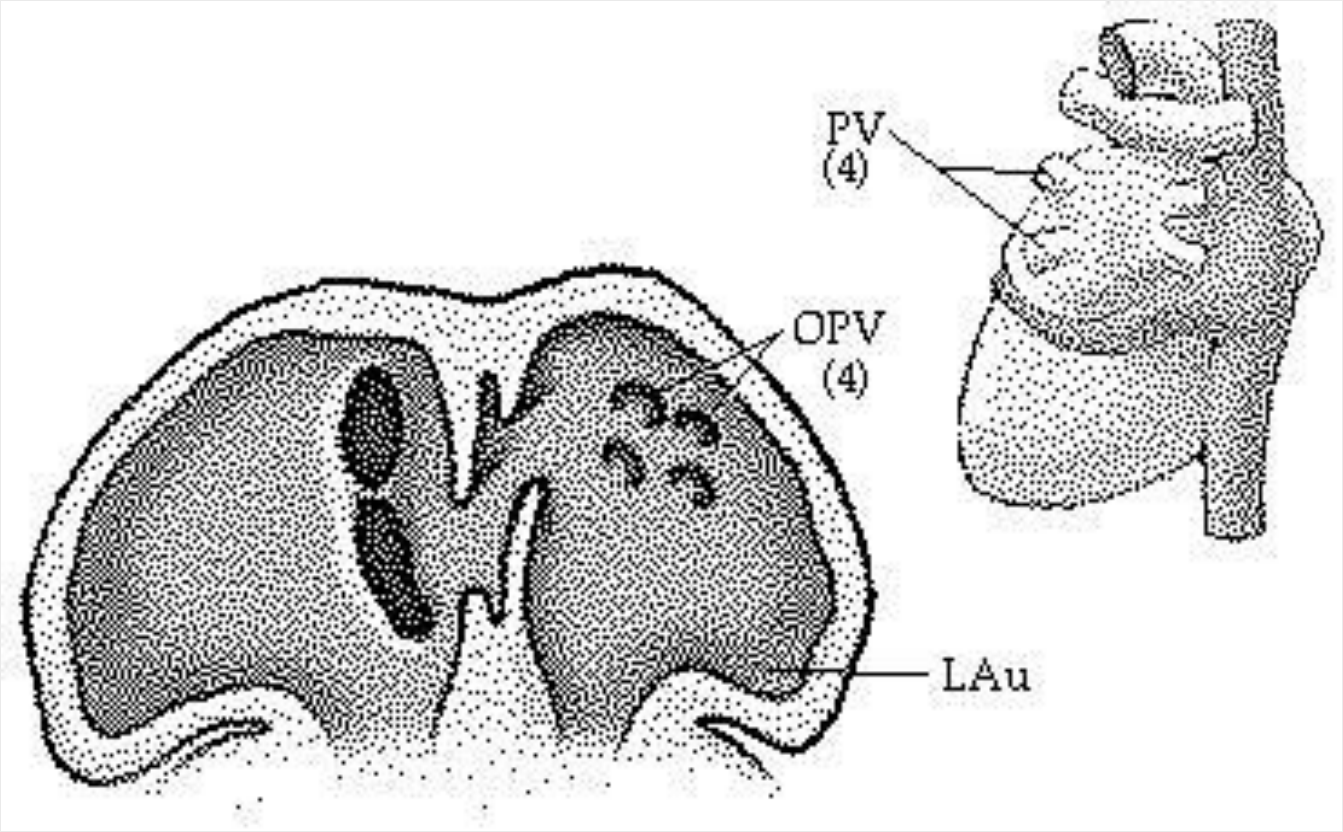
- LA = Left atrium
- OPV = orifice of pulmonary vein
- PV = pulmonary vein



Development of the left atrium occurs concurrently with that of the right atrium. During the early part of the fourth week an outgrowth of the pulmonary veins appear from the left atrium. This "sprout" will bifurcate until there are four veins. These vessels will then grow towards the lung buds.

Pulmonary Veins (Formation of the Left Atrium)

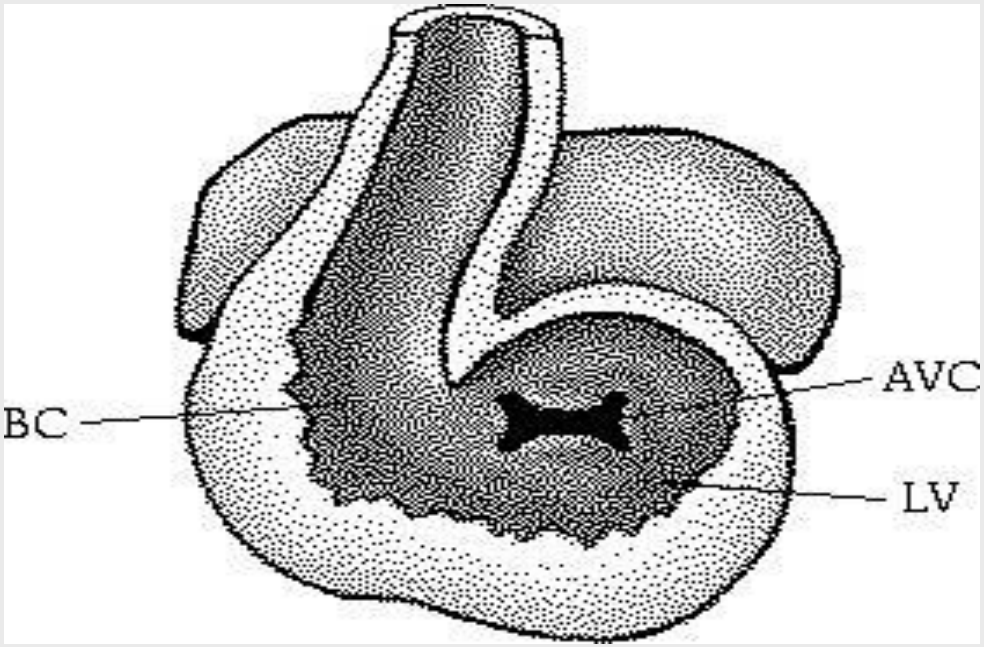
- **LAu** = Left auricle
- **OPV** = Orifice of the four pulmonary veins
- **PV** = four pulmonary veins



The left atrium begins to expand gradually accepting the four branches. As the atrial wall expands, the smooth tissue of the pulmonary veins is incorporated into the wall of the atrium and displaces the trabeculated tissue anteriorly and laterally which will then form the adult auricles. Compare this process to the formation of the adult right auricle.

Atrioventricular Canals

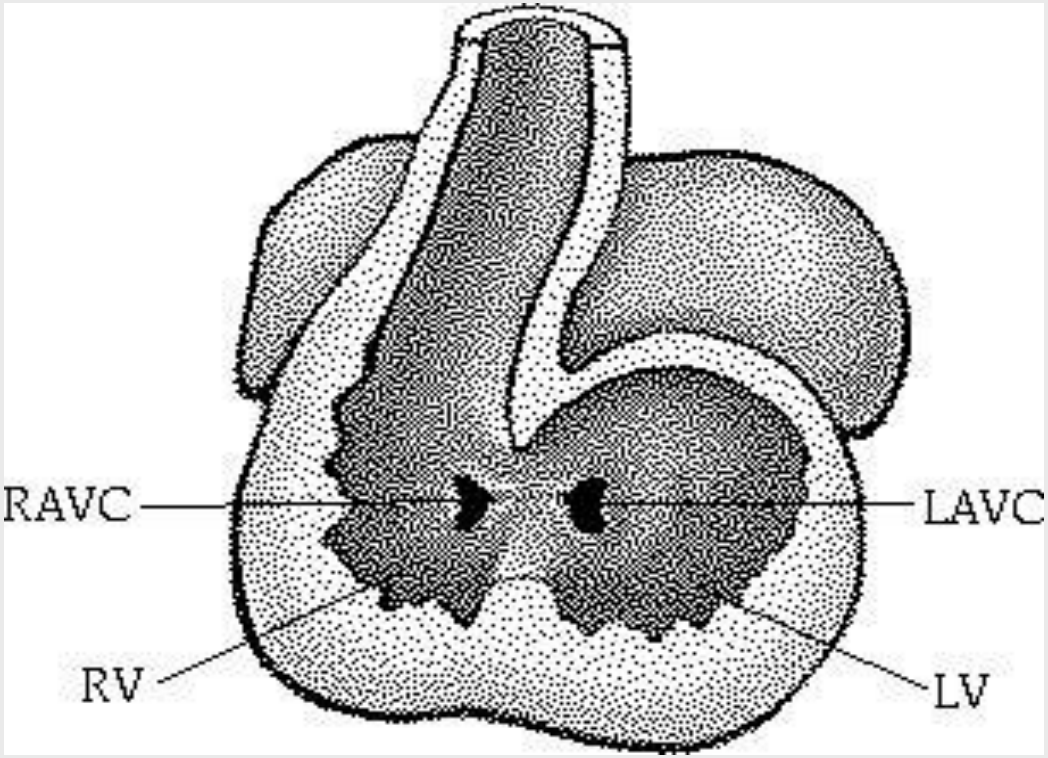
- AVC = Atrioventricular canal
- BC = Bulbus Cordis
- LV = Left ventricle



Recall that the proximal bulbus cordis gives rise to the right ventricle. Thus, blood flows from the primitive atrium to the left ventricle then to the right ventricle. There is no direct communication between the atria and the right ventricle even after the formation of the bulboventriclular loop. The atrioventricular canal must shift to the right in order to acheive communication to the right ventricle in addition to the left ventricle. During this shift the proximal bulbus widens and the bulboventricular flange begins to recede. Swellings of mesenchymal tissue, the endocardial cushions, appear on the borders of the atrioventricular canal. There are four cushions: inferior and superior (ventral and dorsal), left and right. The first appear before the latter. These swellings give the atrioventricular canal a "dog's bone" shape.

Atrioventricular Canals

- **R/LAVC = Right/left atrioventricular canal**



At approximately day 42 the superior and inferior cushions fuse forming a right and a left atrioventricular canal. The left atrium communicates with the left ventricle and the right atrium communicates with the right ventricle. The shifting process brings the conus cordis to lie superior to the interventricular foramen, which at this point, has not yet been obliterated. The fused endocardial cushions are also responsible for the closure of the ostium primum by fusing with the free edge of the septum primum.

Formation of the Aorta and Pulmonary Tract

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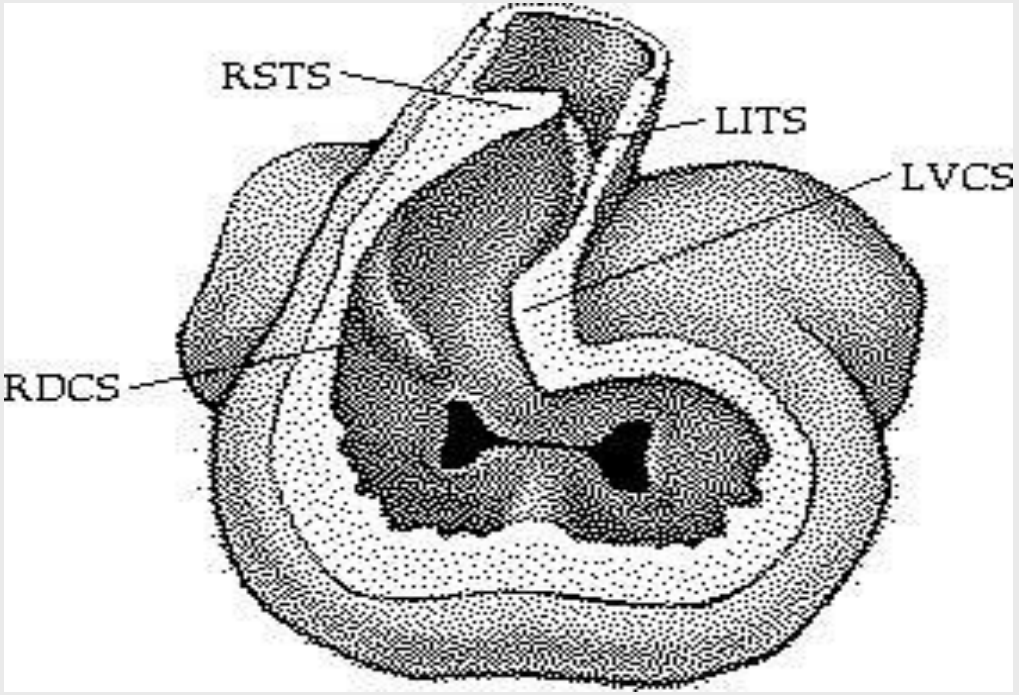
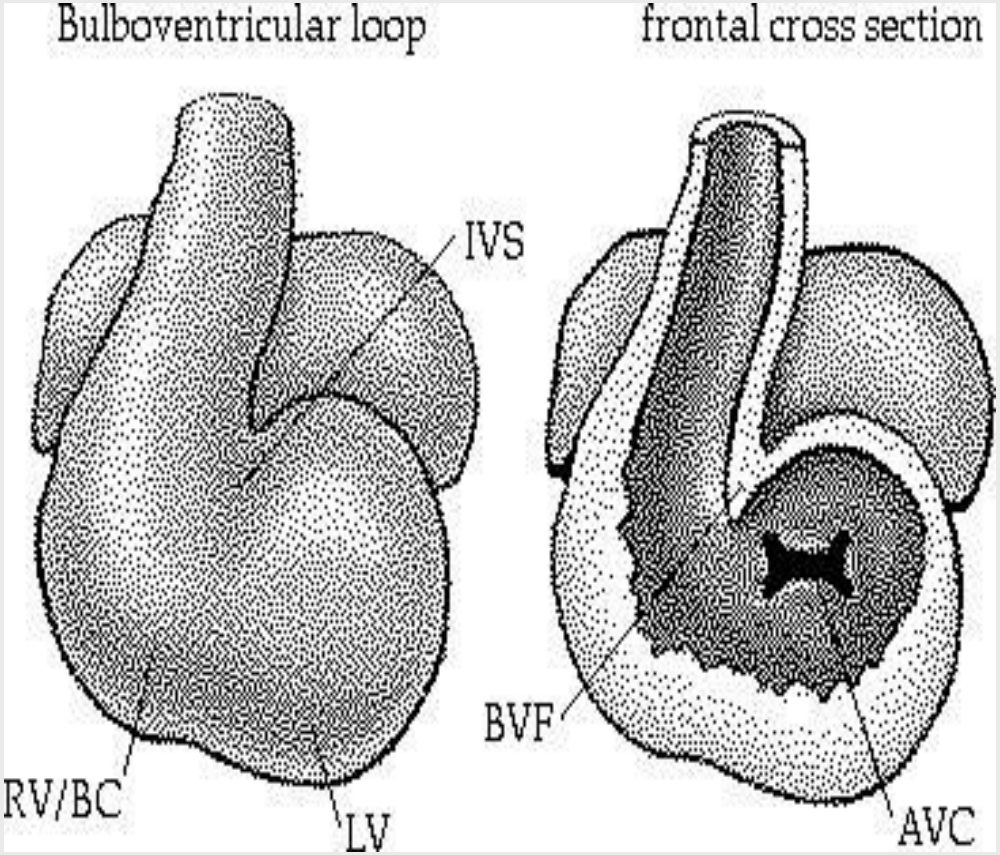


The final morphological change in the heart is the partitioning of the outflow tract - - the truncus arteriosus and the conus cordis - - into the aorta and the pulmonary trunk. This is accomplished by the development of a septum that forms in the outflow tract and the emergence of the two great vessels.

The septum forms from two pairs of swellings which grow from the walls of the outflow tract. These are the ***truncus swellings*** and the ***conus swellings***.

Formation of the Ventricles

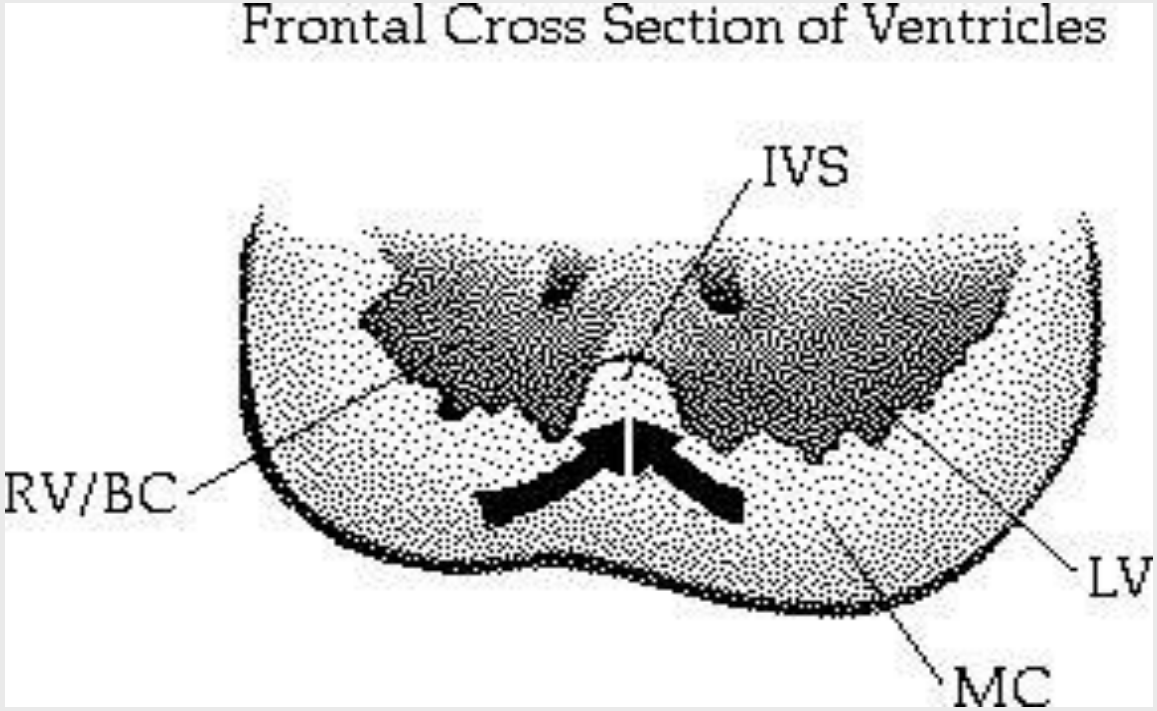
- AVC = Atrioventricular canal
- BC = Bulbus Cordis
- BVF = Bulboventricular flange
- IVS = Interventricular sulcus
- RV = Right ventricle
- LV = Left ventricle



In the newly formed bulboventricular loop the primitive right and left ventricles appear as expansions in the heart tube. Externally the interventricular sulcus separates the right and left ventricles and internally they are separated by the bulboventricular flange. Remember that the right ventricle arises from the proximal bulbus cordis.

Formation of the Ventricles

- BC = Bulbus cordis
- IVS = Interventricular septum
- MC = Myocardium
- RV = Right ventricle



During the shifting of the atrioventriclar canal the proximal bulbus cordis expands forming the right ventricle. Both ventricles will continue to expand until the late 7th/early 8th week. The growth of the ventricles is due to the centrifugal growth of the myocardium and the diverticulation of the internal walls. (This is what gives the ventricle its trabeculated appearance). The muscular interventricular septum forms as a result of the expanding ventricles. The walls of the right and left ventricles grow in opposition to each other to form the muscluar septum. Thus, the septum will cease to grow when the ventriclar walls are no longer expanding.

Atrial Septal Defect

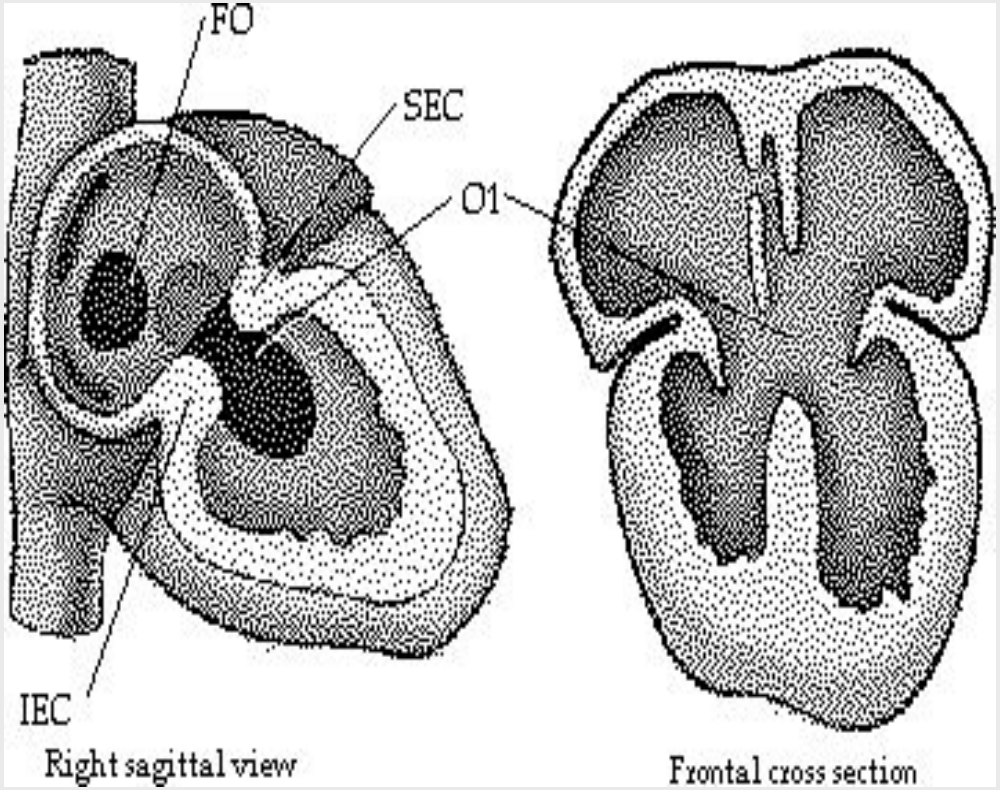
In a heart with an Atrial Septal Defect (ASD) there is communication between the right and left atria which causes a left to right shunting of blood due to the lower pressure in the pulmonary circulatory system. Consequently there is a mixing of oxygenated (systemic) and deoxygenated (pulmonary) blood.

There are two types of ASD:

- Primum type involves the endocardial cushions.
- Secundum type involves septum primum or septum secundum.

Primum Type ASD

- FO = Foramen ovale
- IEC = Inferior endocardial cushion
- SEC = Superior endocardial cushion
- O1 = ostium primum



In this case, the ostium primum is patent because the septum primum does not fuse with the endocardial cushions. Recall that the cushions are responsible in forming a portion of septum primum, thus obliterating ostium primum.

Formation of the Aorta and Pulmonary Tract

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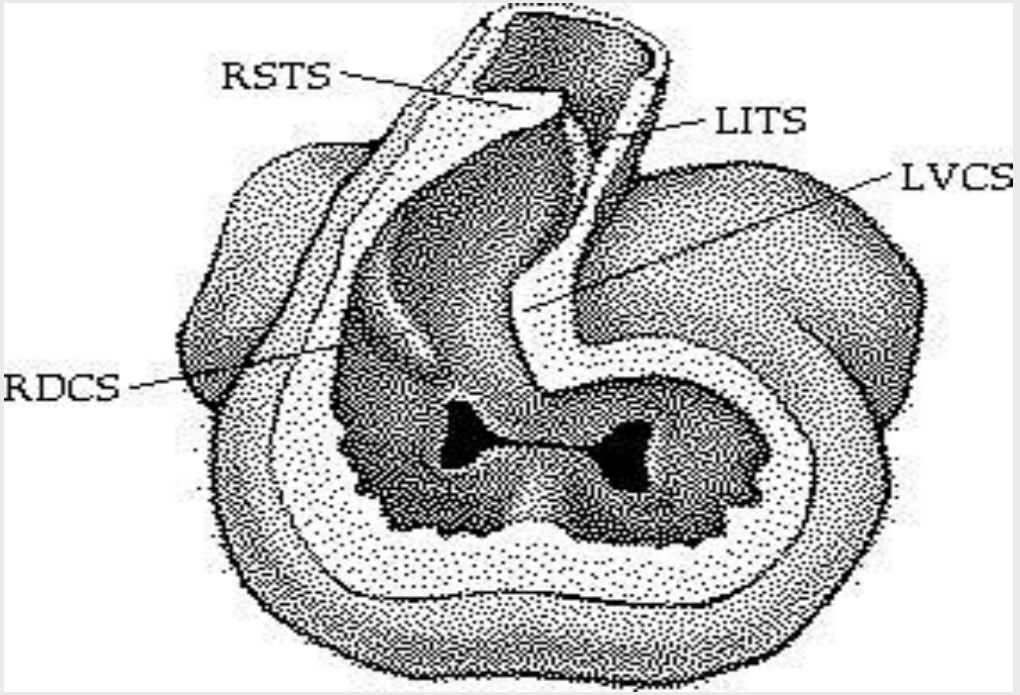
- **RDCS/ LVCS = Right dorsal/ Left ventral conus swelling**



Truncal swellings: *Right superior* which grows distally and to the left. *Left inferior* which grows distally and to the right. Both develop at the proximal part of the truncus and proceed to grow in two directions; 1) distally towards the aortic sac and 2) into the lumen of the outflow tract where they will eventually fuse together.

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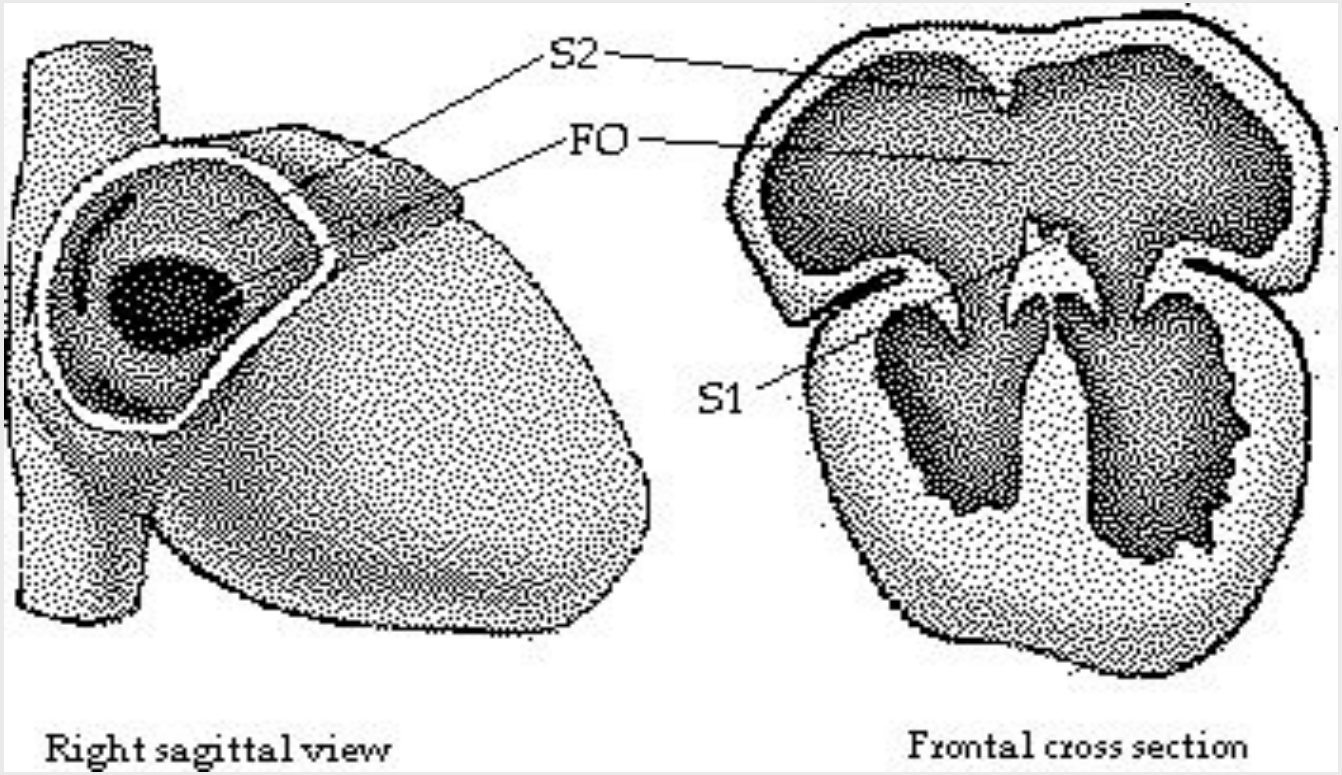
Secundum Atrial Septal Defect

- FO = Foramen ovale
- S1 = Septum primum
- S2 = Septum secundum

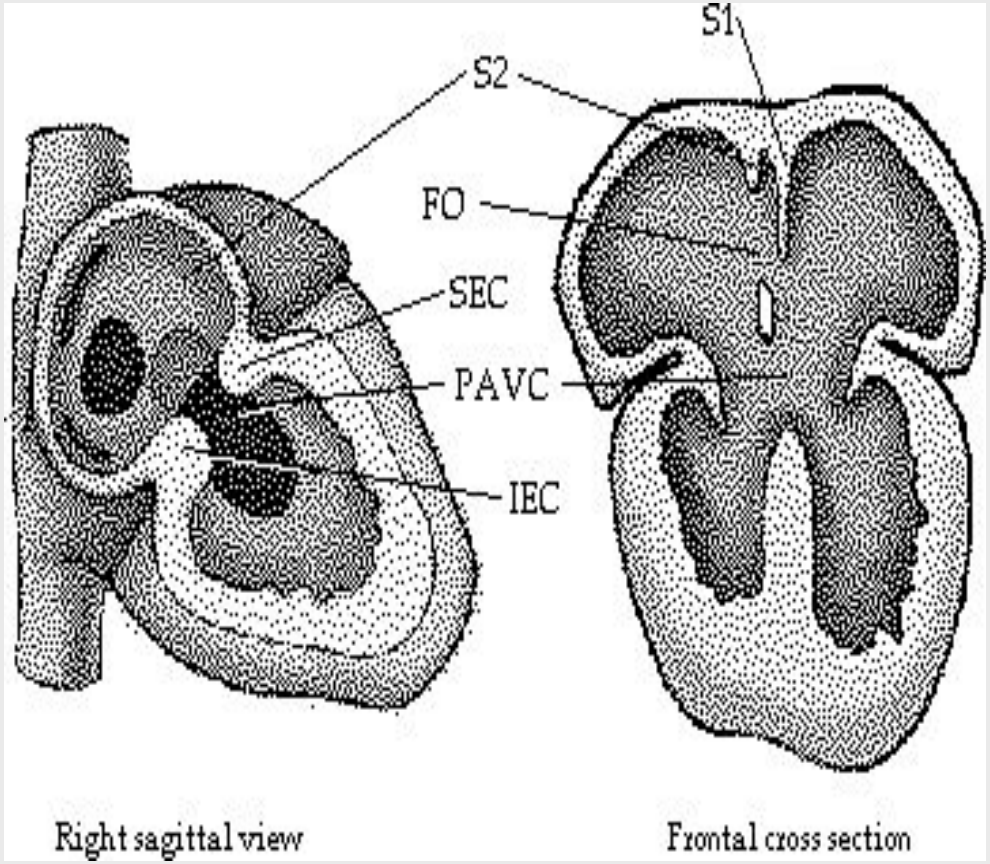


This type involves septum primum and/or septum secundum. In both cases the result is a patent foramen ovale.

There may be excessive resorbtion of septum primum where very little septum remains or it has been completely resorbed. The short septum primum does not overlap the foramen ovale leaving a communication between right and left atrium. If the septum secundum is involved it is because it did not reach its full growth and thus results in a large foramen ovale.

Persistent Atrio-ventricular Canal

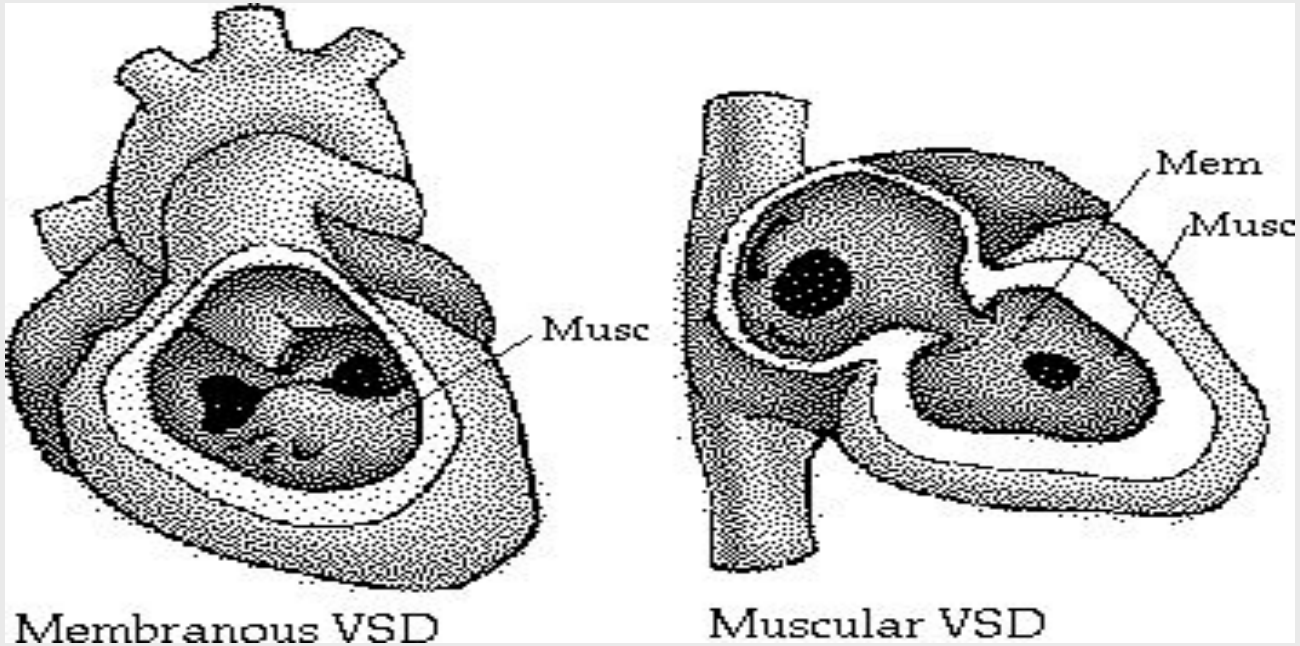
- IEC = Inferior endocardial cushion
- SEC = Superior endocardial cushion
- PAVC = Persistent atrioventricular canal
- S1 = Septum primum
- S2 = Septum secundum



The persistent atrioventricular canal results from the failure of the superior and inferior cushions to fuse. Thus there is a single atrioventricular canal in which all four chambers may freely communicate. Because the cushions do not fuse the atrial and ventricular septa cannot fully form as they rely on the cushions to form the membranous portions of these septa.

Ventricular Septal Defect

- Mem = Membranous septum
- Musc = Muscular septum



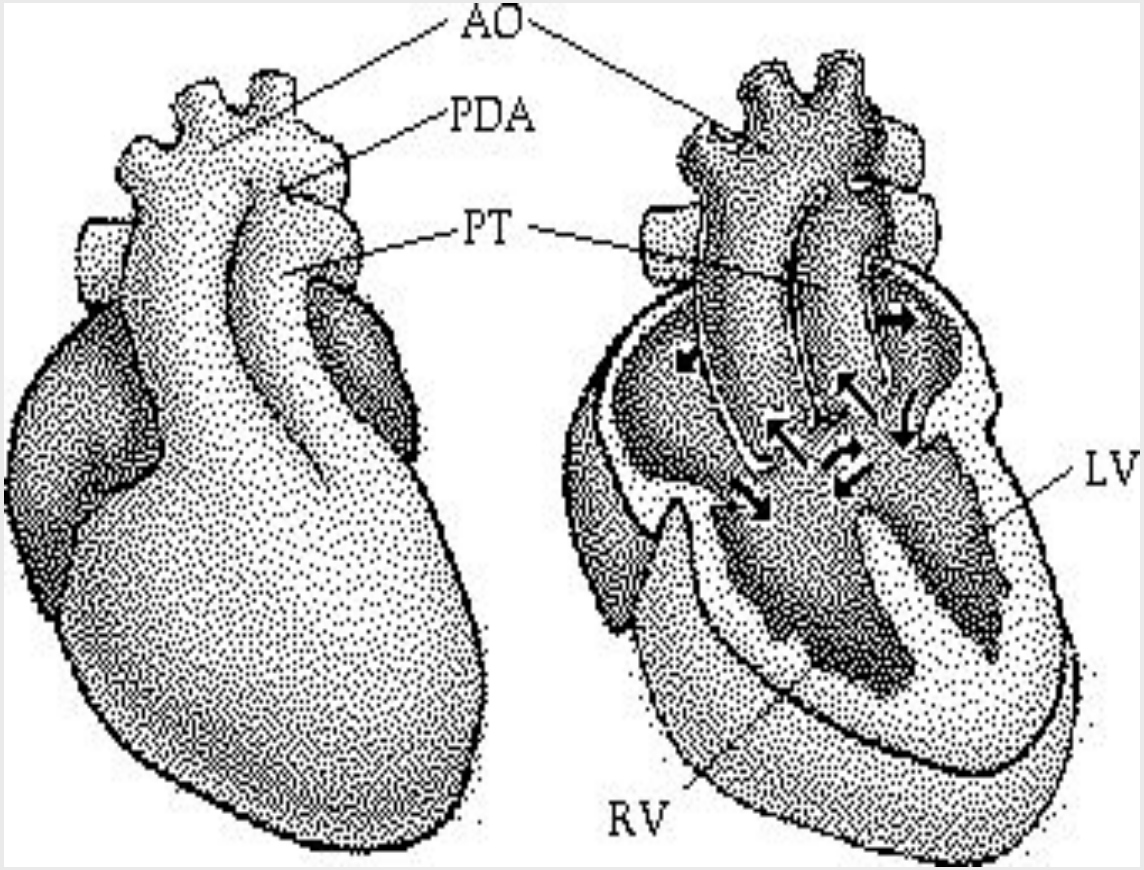
The ventricular septal defect is the most common of all congenital heart anomalies. It may be caused by any of the four malformations:

1) Deficient development of the proximal conus swellings.
2) Failure of the muscular portion of the interventricular septum to fuse with the free edge of the conus septum. (Membranous VSD)
3) Failure of the endocardial cushions to fuse.
4) Excessive diverticulation of the muscular septum- perforations in the muscular interventricular septum. (Muscular VSD)

In the case of a VSD there is a massive left to right shunting of blood and pulmonary hypertension. The absence of the interventricular septum results in a Common Ventricle.

Transposition of the Great Vessels

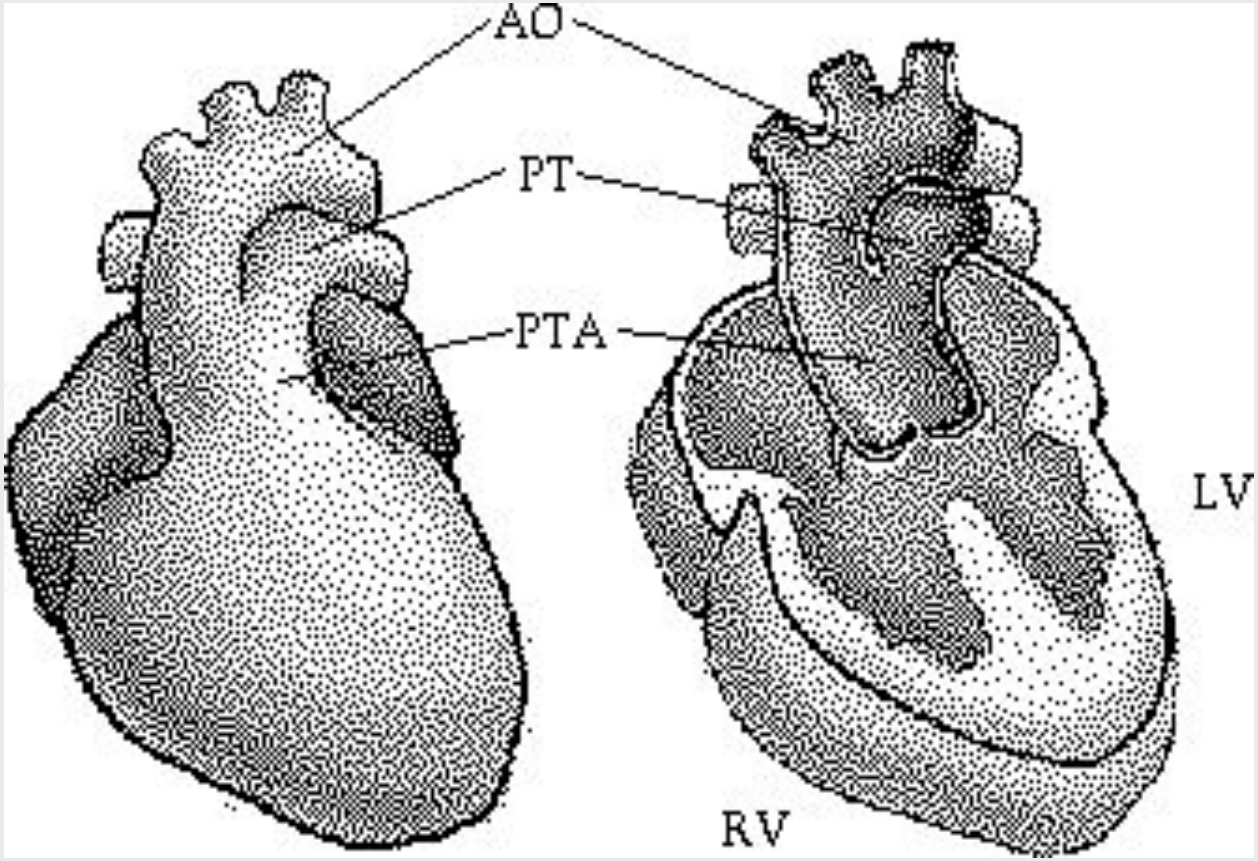
- AO = Aorta
- PT = Pulmonary trunk
- PDA = Persistent Dunctus Arteriosus
- RV/LV = right and left ventricles



Transposition is a condition in which the aorta arises from the right ventricle and the pulmonary trunk from the left. This anomally is due to the failure of the truncoconal swellings to grow in the normal spiral direction. There is also a ventricular septal defect and a patent ductus arteriosus. However, these secondary defects make life possible as they provide a way for oxygenated blood to reach the entire body.

Persistent Truncus Arteriosus

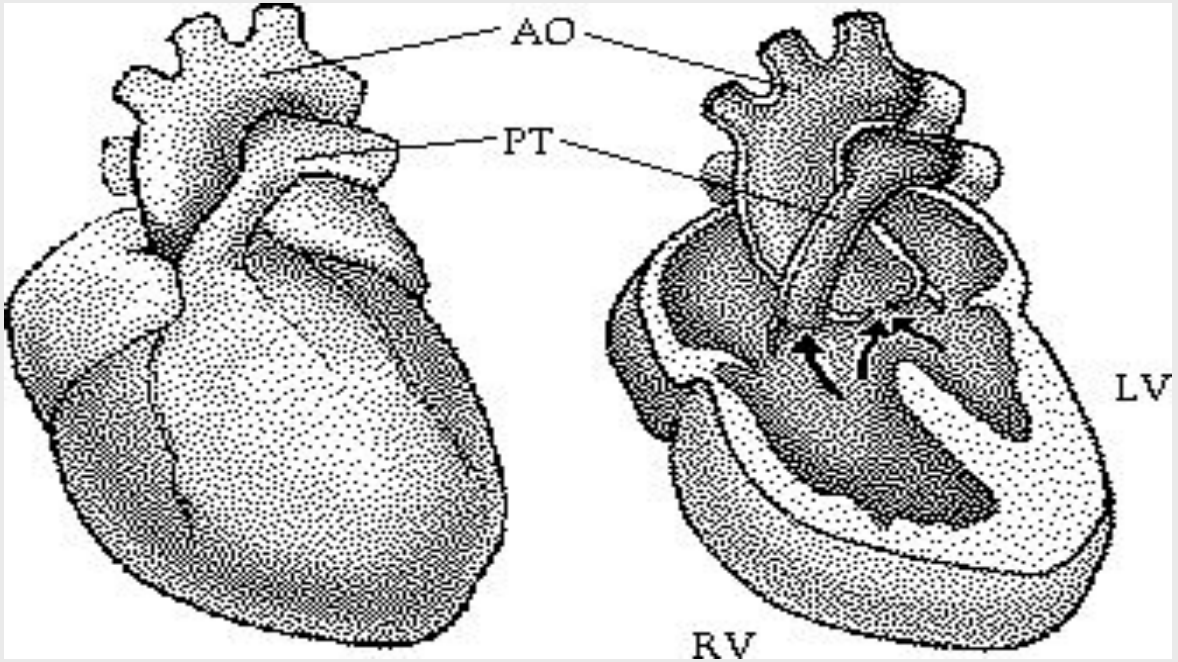
- AO = Aorta
- PT = Pulmonary trunk
- PTA = Persistent truncus arterio-sus
- RV/LV = Right and left ventricles



A persistent truncus arteriosus results when the truncoconal swellings fail to grow. The single artery, the truncus arteriosus, arises from both ventricles above the ventricular septal defect, allowing pulmonary and systemic blood to mix. Distally, the single artery is divided into the aorta and pulmonary trunk by an incomplete septum.

Tetralogy of Fallot

- AO = Aorta
- PT = Pulmonary trunk (stenotic)
- RV/LV = Right and left ventricles

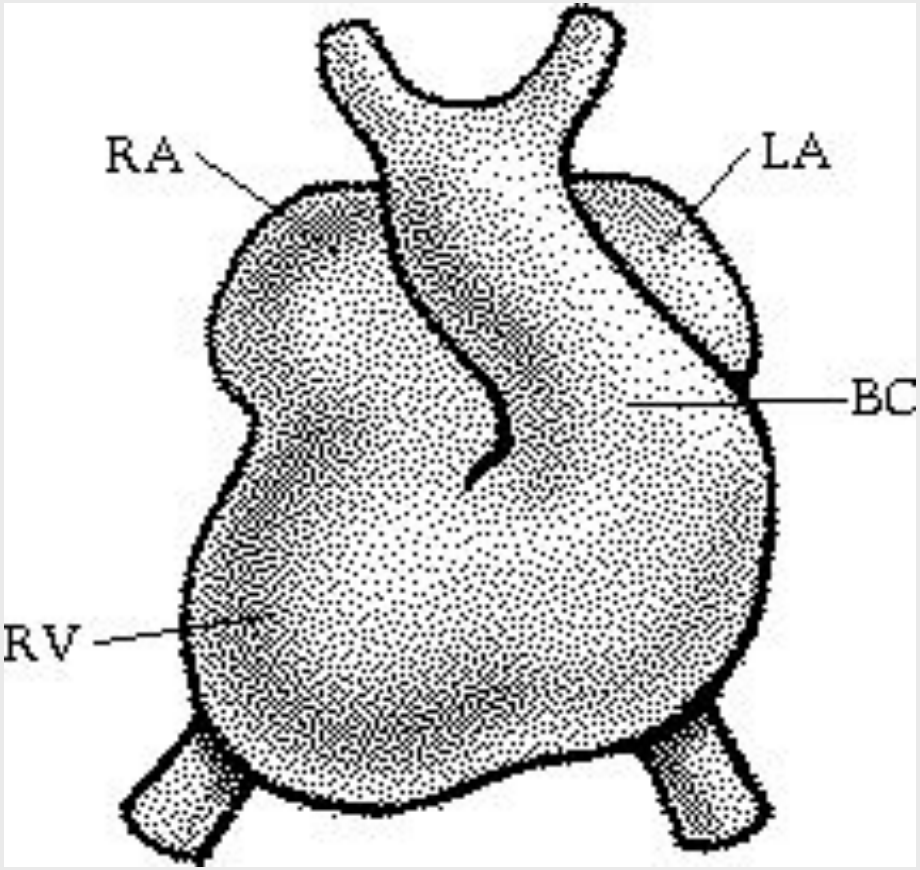


This condition results from a single error: the conus septum develops too far anteriorly giving rise to two unequally proportioned vessels- - a large aorta and a smaller stenotic pulmonary trunk. The four main characteristics of Tetralogy of Fallot are:

1) pulmonary stenosis
2) ventricular septal defect (VSD) of the membranous portion (the septum is displaced too far anteriorly to contribute to the septum)
3) overriding aorta (the aorta straddles the VSD)
4) right ventricular hypertrophy due to the shunting of blood from left to right. (The pressure in the right ventricle is increased causing the walls of the right ventricle to expand.)

Dextrocardia

- RA/LA = Right and left atrium
- RV = Right ventricle
- BC = Bulbus cordis



Dextrocardia is an anomaly in which the primitive heart tube folds to the left in a mirror image of a normal bulboventricular loop. This usually occurs when all the organ systems are reversed, a condition called *situs inversus*.

Time-Line Schedule of Heart Development

Stage 11

13-20 Somite Pairs, Rostral Neuropore Closes, Optic Vesicle

Appears,

Two Pharyngeal Arches Appear
2.5 - 3.0 mm
23 - 25 days post-ovulation

The embryo is shaped in a modified S curve. The embryo has a bulb-like tail and a connecting stalk to the developing placenta.
A primitive S-shaped tubal heart is beating and peristalsis, the rhythmic flow propelling fluids throughout the body, begins. However, this is not true circulation because blood vessel development is still incomplete.

MAIN STAGES OF THE ERALY HEART DEVELOPMENT

The heart tube begins to grow rapidly forcing it to bend upon itself.

The result is the bulboventricular loop.

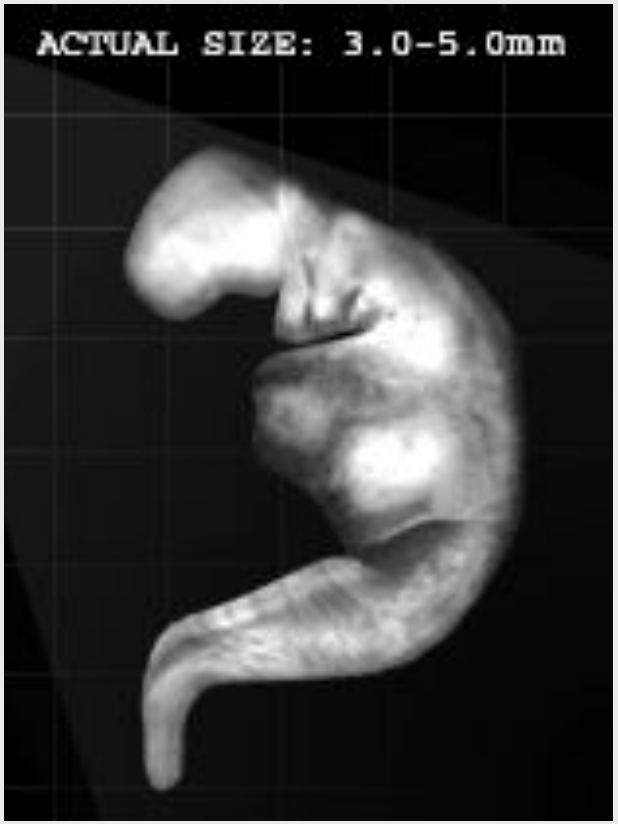
Septa begin to grow in the atria, ventricle and bulbus cordis to form right and left atria, right and left ventricles and two great vessels- the pulmonary artery and the aorta.

By the end of the eighth week partitioning is completed and the fetal heart has formed.

Stage 13 (approximately 27-29 postovulatory days)
Four Limb Buds, Lens Disc and Optic Vesicle, the first thin surface layer of skin appears covering the embryo. 30-40 somite pairs.

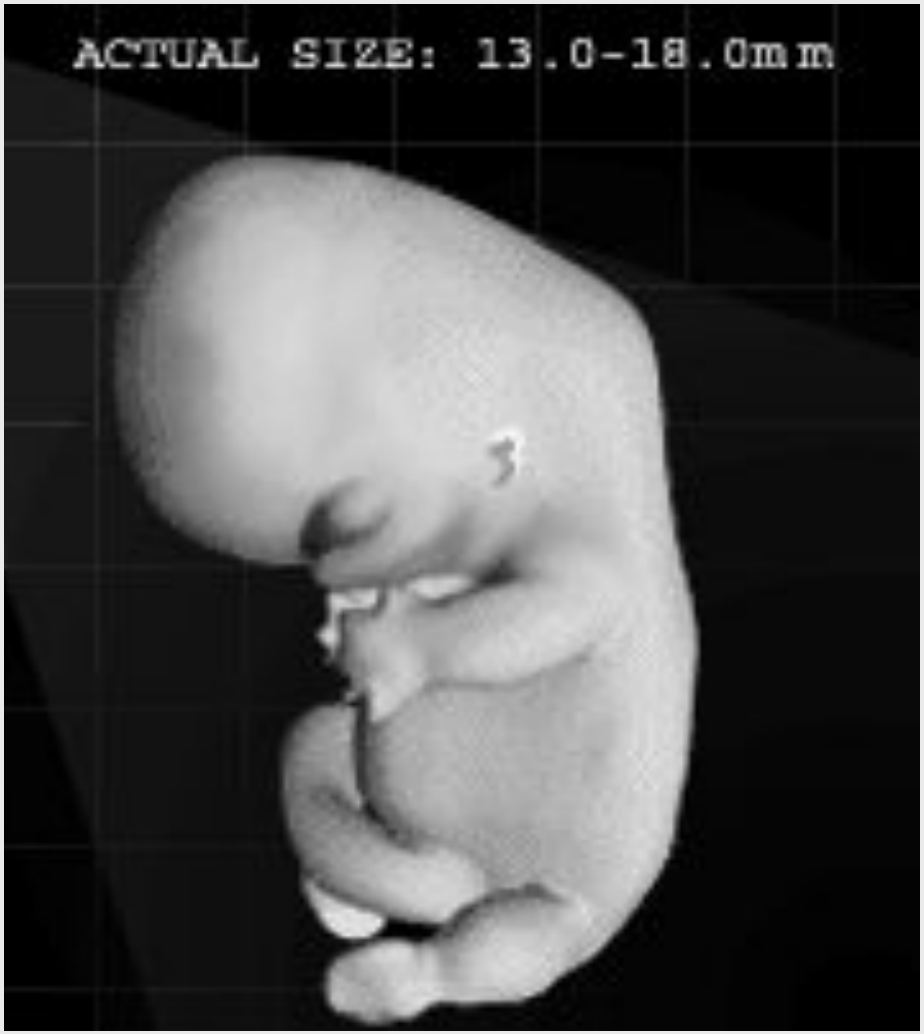
Heart chambers are filled with plasma and blood cells making the heart seem distended and prominent. The heart and liver combined are equal in volume to the head by this stage. Blood circulation is well established, though true valves are not yet present.

Stage 12
21-29 Somite Pairs,
Caudal Neuropore
Closes, Three to Four
Pharyngeal Arches
Appear, Upper Limb
Buds Appear
3.0 - 5.0 mm
25 - 27 days
post-ovulation



The embryo curves into a C shape. The arches that form the face and neck are now becoming evident under the enlarging forebrain. A blood system continues to develop. Blood cells follow the surface of yolk sac where they originate, move along the central nervous system, and move in the chorionic villi, the maternal blood system. Valves and septa may appear in the heart in Stage 12.

Stage 19,
(approximately
47-48 post ovulatory days)



Septum primum fuses with septum intermedium in the heart.

Stage 14, 5th week

Lens Pit and
Optic Cup
Appear,
Endolymphatic
Appendage
Distinct

Semilunar valves begin to form in the heart. Four major subdivisions of the heart (the trabeculated left and right ventricles, the conus cords and the truncus arteriosus) are clearly defined. Two sprouts, a ventral one from the aortic sac and a dorsal one from the aorta, form the pulmonary (sixth aortic) arch.

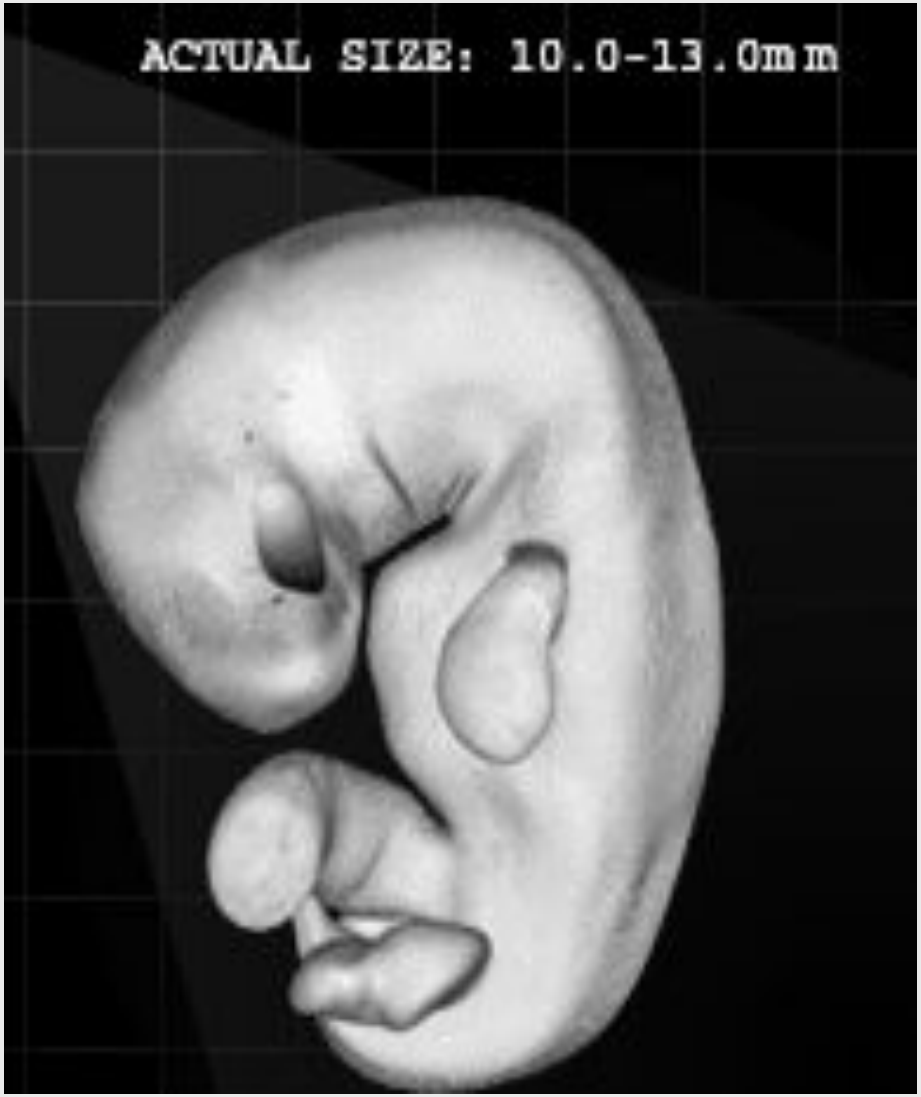
Stage 15
(6 to 8 weeks post fertilization)
Lens Vesicle, Nasal Pit, Hand Plate; Trunk Widens, Future Cerebral Hemispheres Distinct

Blood flow through the arioventricular canal is divided into left and right streams, which continue through the outflow tract and aortic sac. The left ventricle is larger than the right and has a thicker wall.

Stage 16
(6th weeks post fertilization)

Primary cardiac tube separates into aortic and pulmonary channels and the ventricular pouches deepen and enlarge, forming a common wall with their myocardial shells.

Stage 17 (approximately 41 postovulatory days) A Four Chambered Heart and a Sense of Smell



The heart begins to separate into four chambers.

Stage 18, 44 days
Ossification of the Skeleton Begins

Within the heart, the trunk of the pulmonary artery separates from the trunk of the aorta.

CONGENITAL MALFORMATIONS OF THE HEART AND GREAT VESSELS.

1. **They are common.**
2. **The overall incidence is 0.7% of live births and 2.7% of stillbirths.**

- **Atrial Septal Defects (ASD) – are among the most common (6.4/10,000births).**
- **One of the most significant defects is ostium secundum defect. This anomaly is characterized by a large opening between the left and the right atria and is caused either by excessive cell death or resoption of the septum primum. Or by inadequate development of the septum secundum. Depending on the size of the opening considerable intercardiac shunting may occur from left to the right.**

Ventricular Septal Defects involve the membranous portion of the septum. The occur in 12/10,000.

Depending on the size of the opening, blood carried by the pulmonary artery may be 1.5 times more abundant than that carried by aorta. The defect may be not restricted to the membranous part and involve the muscular part of the septum.

Tetralogy of Fallot is the most frequently occured abnormality of the conotruncal region. The defect is due to an unequal division of the conus, resulting from anterior displacement of the conotruncal septum. Displacement of the septum produces four CV-alterations:

-a narrow right ventricular outflow region,i.e. Pulmonary infundibular stenosis,

-a large defect of the interventricular septum,

-an overriding aorta that arrises directly above the septal defect,

-hypertrophy of the right ventricular wall due to the hight pressure on the right side. The rate is 9.6/10,000.