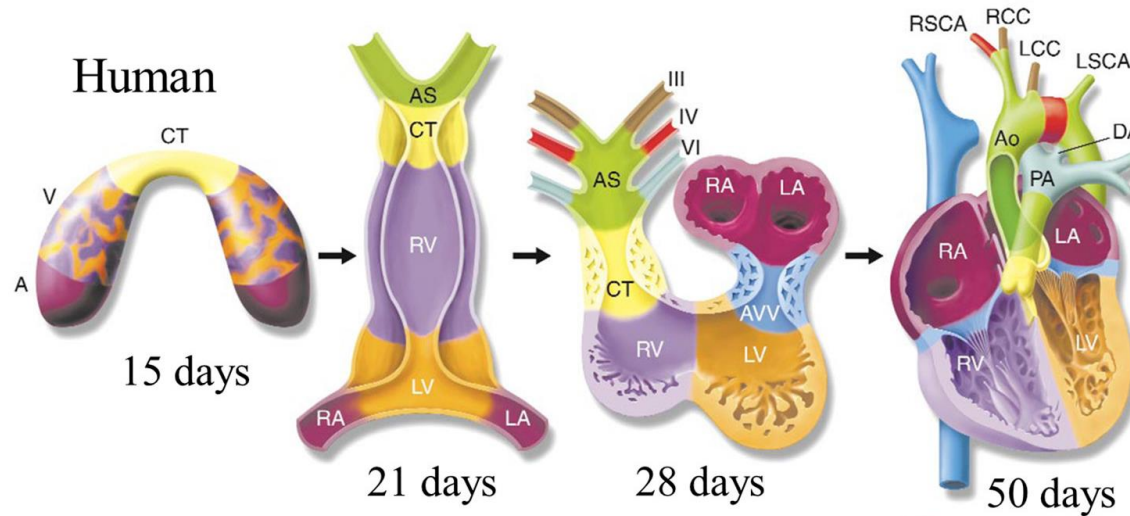


# DEVELOPMENT OF CARDIOVASCULAR SYSTEM



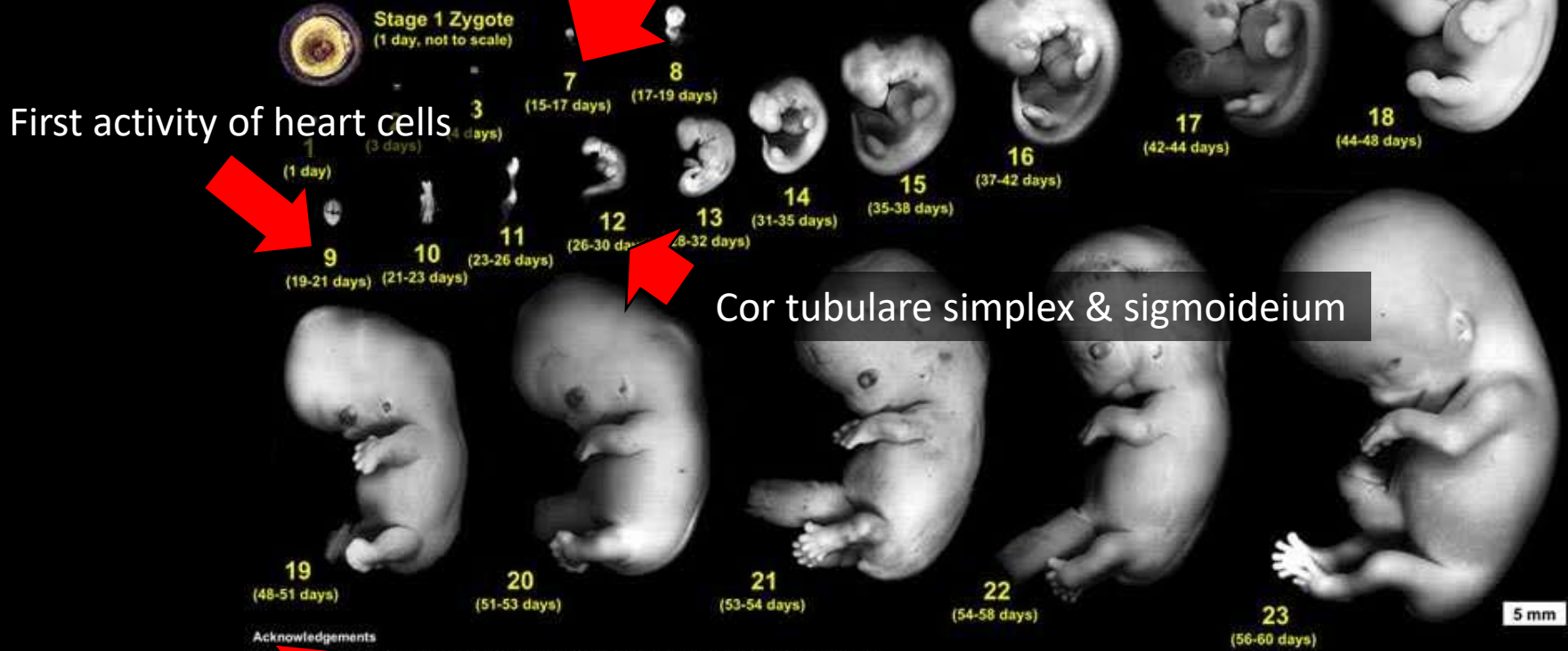
Petr Vaňhara

# DEVELOPMENT OF CARDIOVASCULAR SYSTEM

First morphological hallmarks of developing heart

## Carnegie Stages of Human Development

Dr Mark Hill, Cell Biology Lab, School of Medical Sciences (Anatomy), UNSW



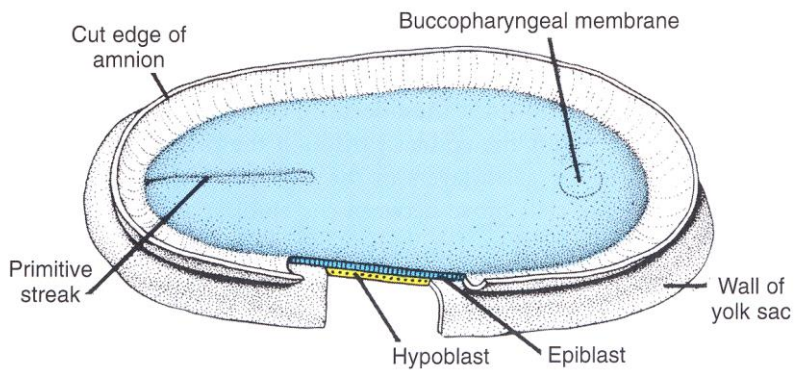
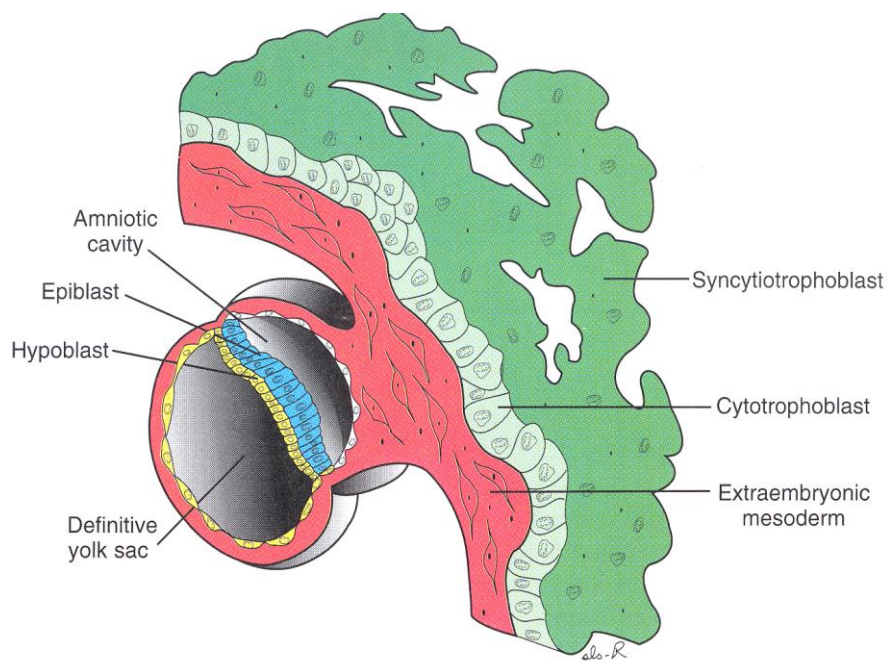
First activity of heart cells

Cor tubulare simplex & sigmoideium

Fully functional, four-chamber heart

Acknowledgements  
Special thanks to Dr S. J. DiMarzo and Prof. Kohel Shiota for allowing reproduction of their research material from the Kyoto Collection and Ms B. Hill for image preparation.  
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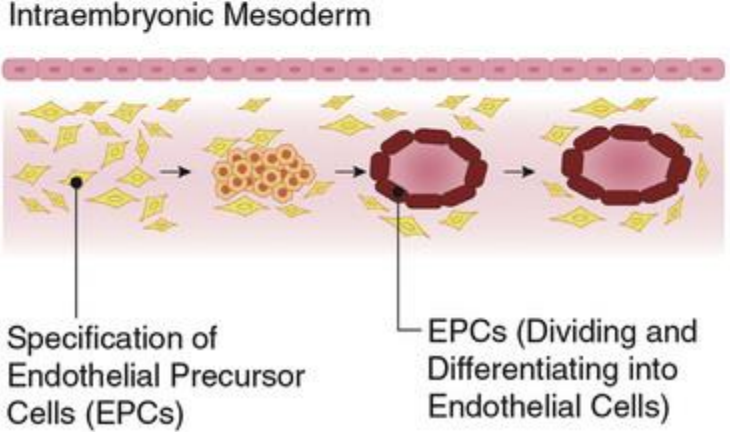
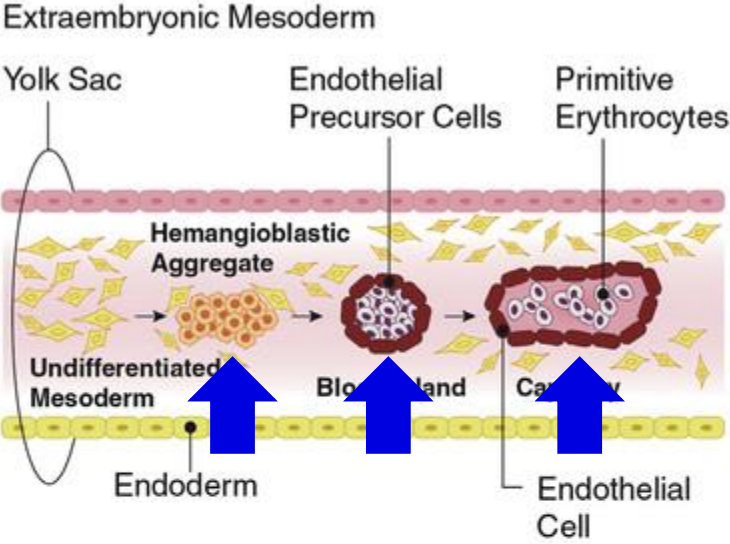
Week 2-3



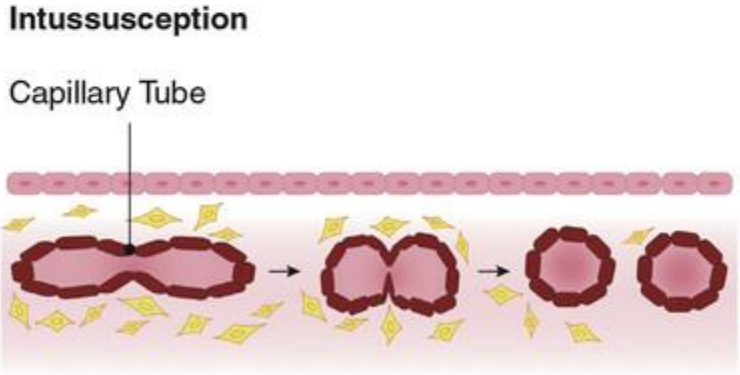
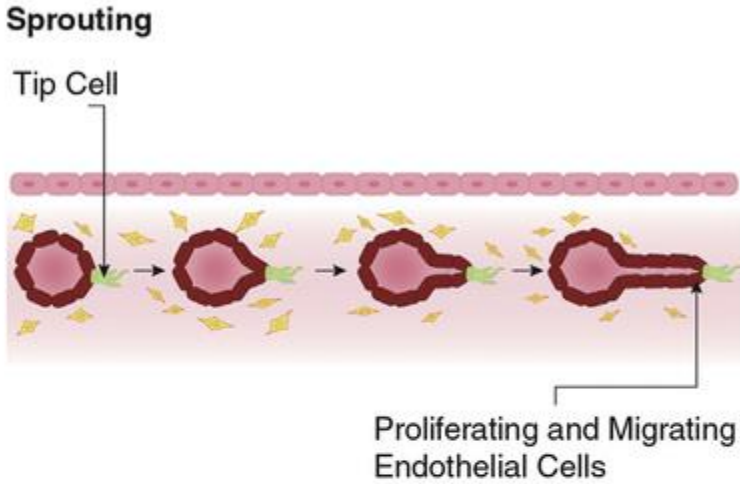


# VASCULOGENESIS AND ANGIOGENESIS

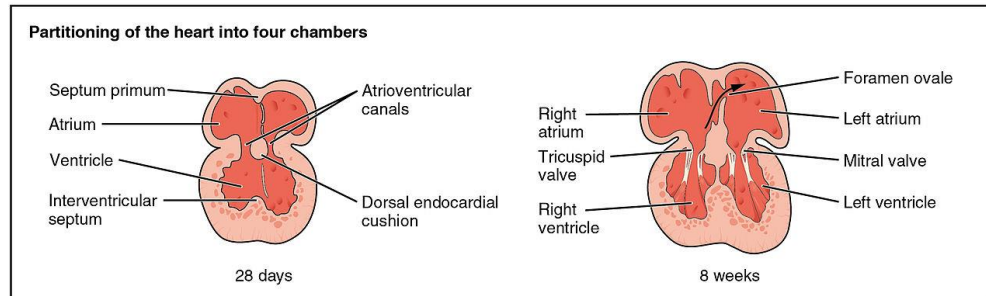
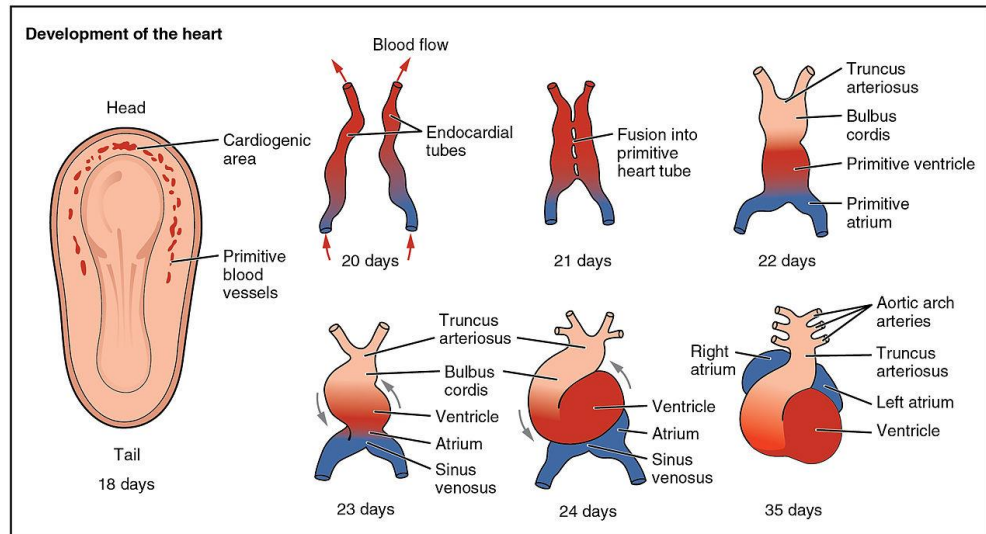
## Vasculogenesis



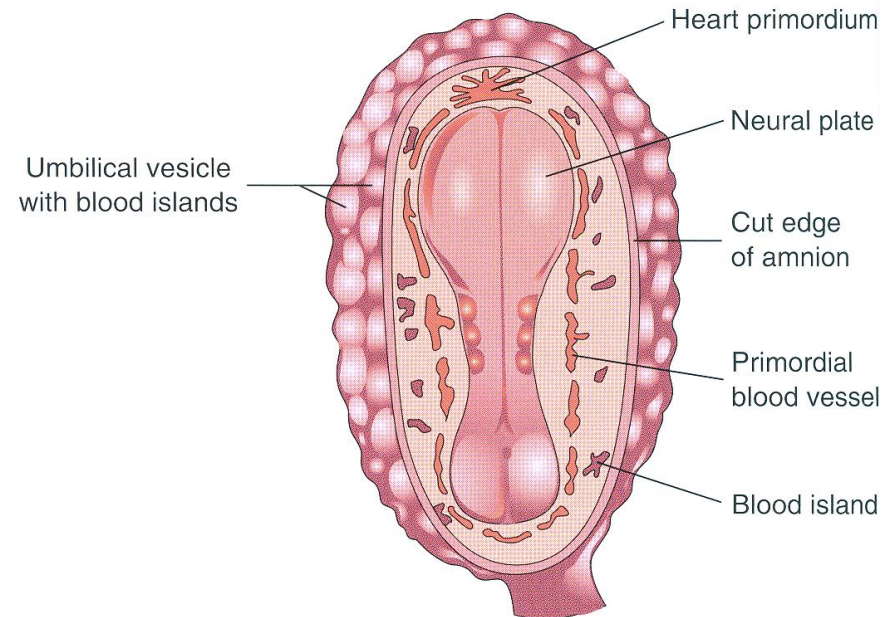
## Angiogenesis



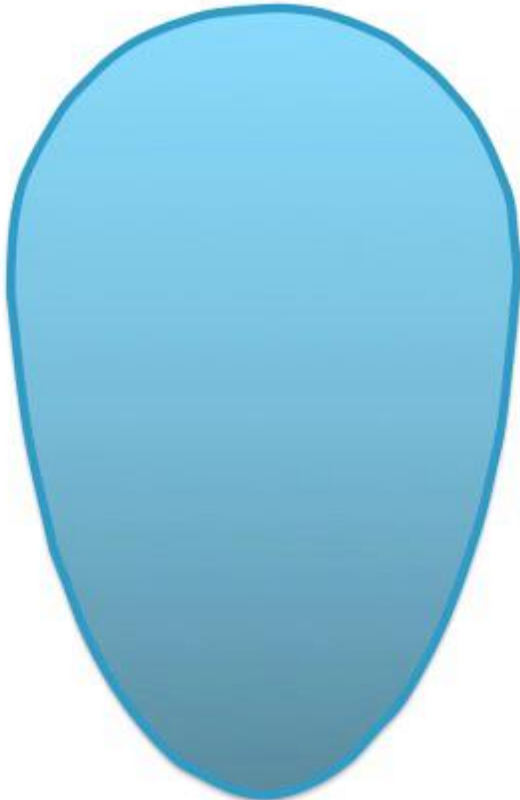
# Development of heart and the first vasculature



- **embryonic vasculogenesis** approx. 2 days later after establishment of extra-embryonic vessels
- primordial blood vessels
- **heart primordium** in cardiogenic area → **endocardial tubes**
- embryonic hematopoiesis from para-aortic clusters in AGM



Week 3

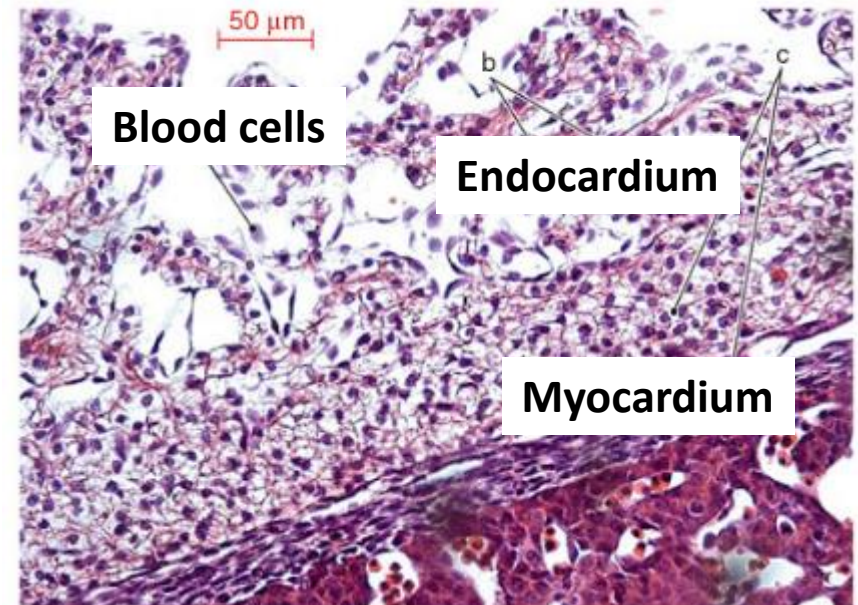
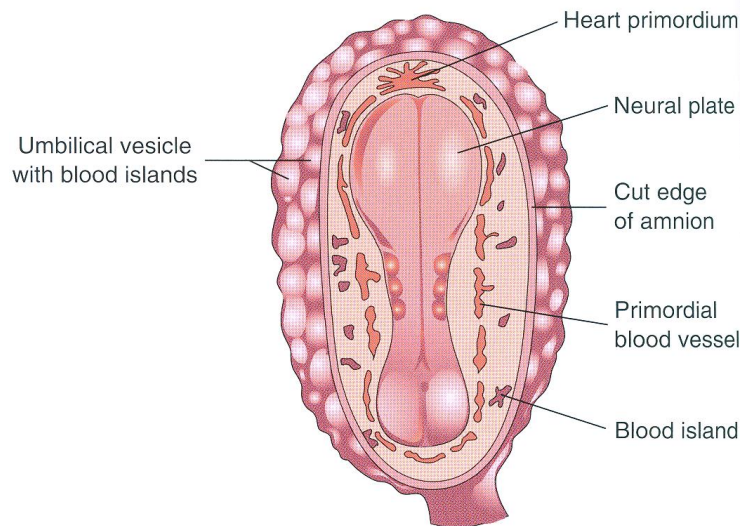


**Epiblast**  
*18 days, dorsal surface*



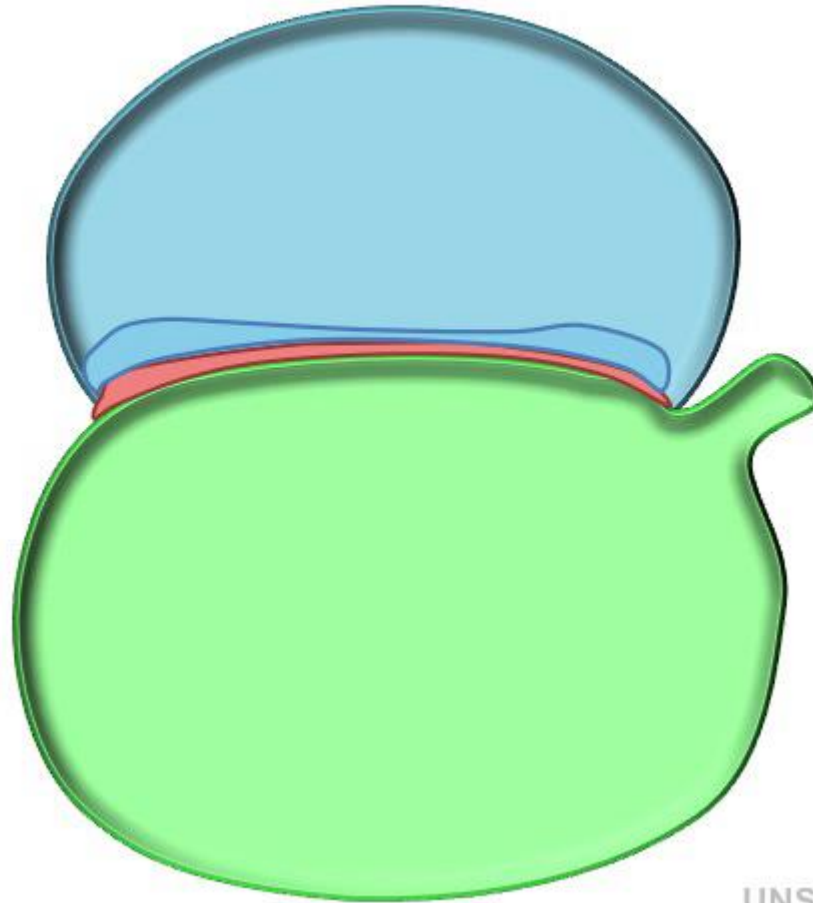
### Development of primitive heart

- paired endocardial **heart tubes (cor tubulare duplex)** derived from embryonic splanchnopleura in cardiogenic area
- flexion of the embryo → medial fusion of paired tubes into **simple-tubular heart (cor tubulare simplex)**
- visceral mesoderm constitutes **myoepicardial layer: myocardium** and **epicardium**
- **cardiac jelly** → subendocardial connective tissue
- heart starts beating day 21-22
- blood starts flow ~week 4<sup>th</sup>



Week 3-4

## Folding and Fusion of the Heart Tubes

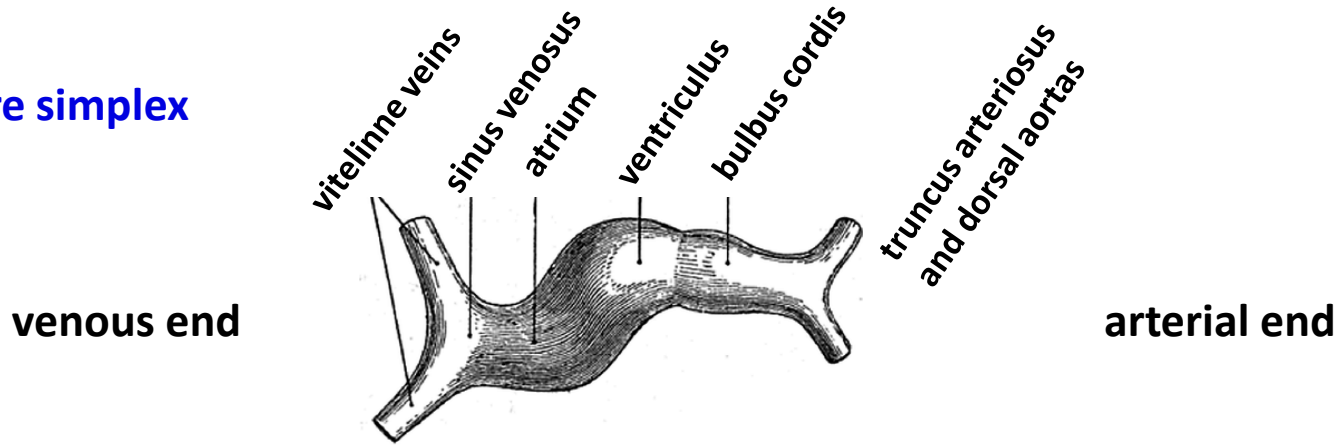


# DEVELOPMENT OF HEART

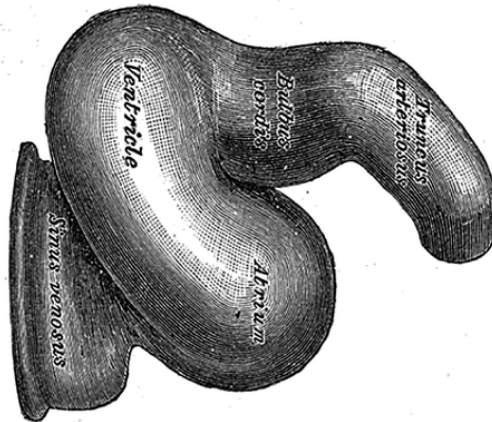
## Week 4

- **simple-tubular heart** (cor tubulare simplex and cor tubulare sigmoideum )
- **sinus venosus → atrium → ventriculus → bulbus cordis → truncus arteriosus**

cor tubulare simplex



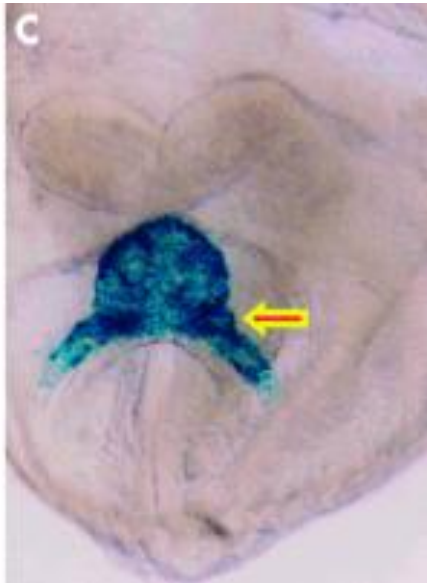
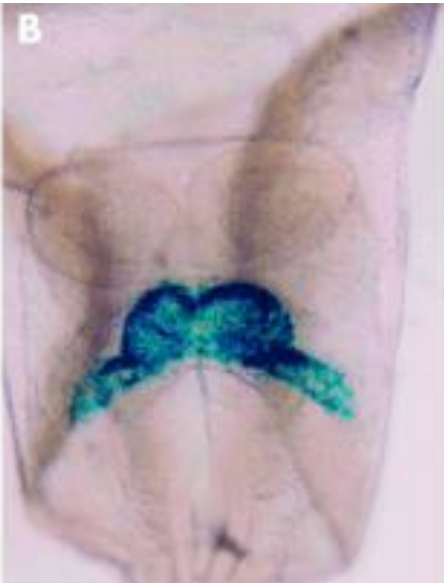
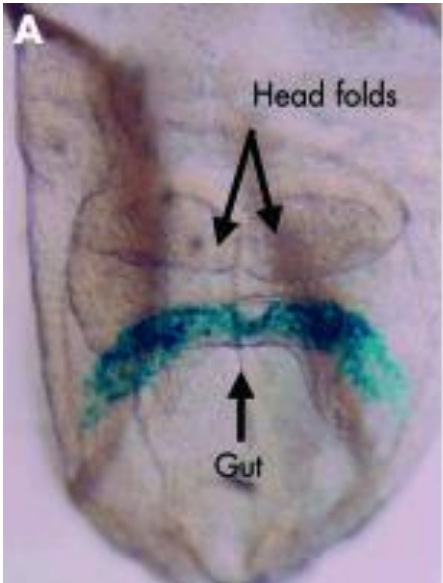
cor tubulare sigmoideum



# DEVELOPMENT OF HEART



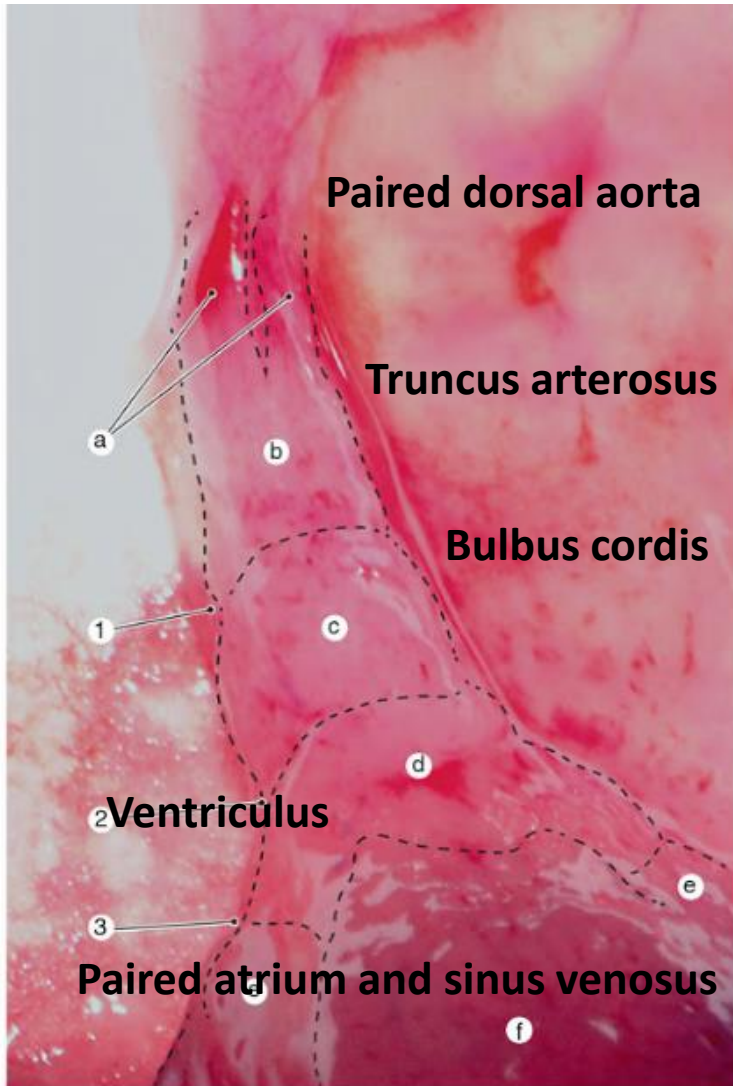
**fusion of endocardial tubes** and development of simple tubular heart



# DEVELOPMENT OF HEART

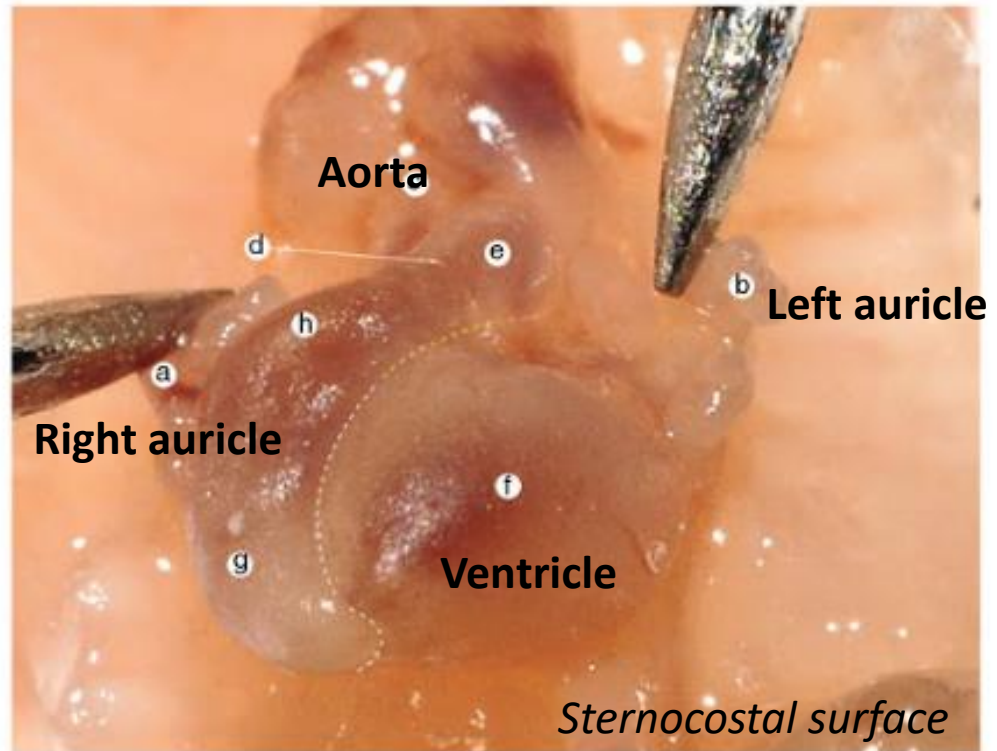
## Week 4

### Cor tubulare simplex

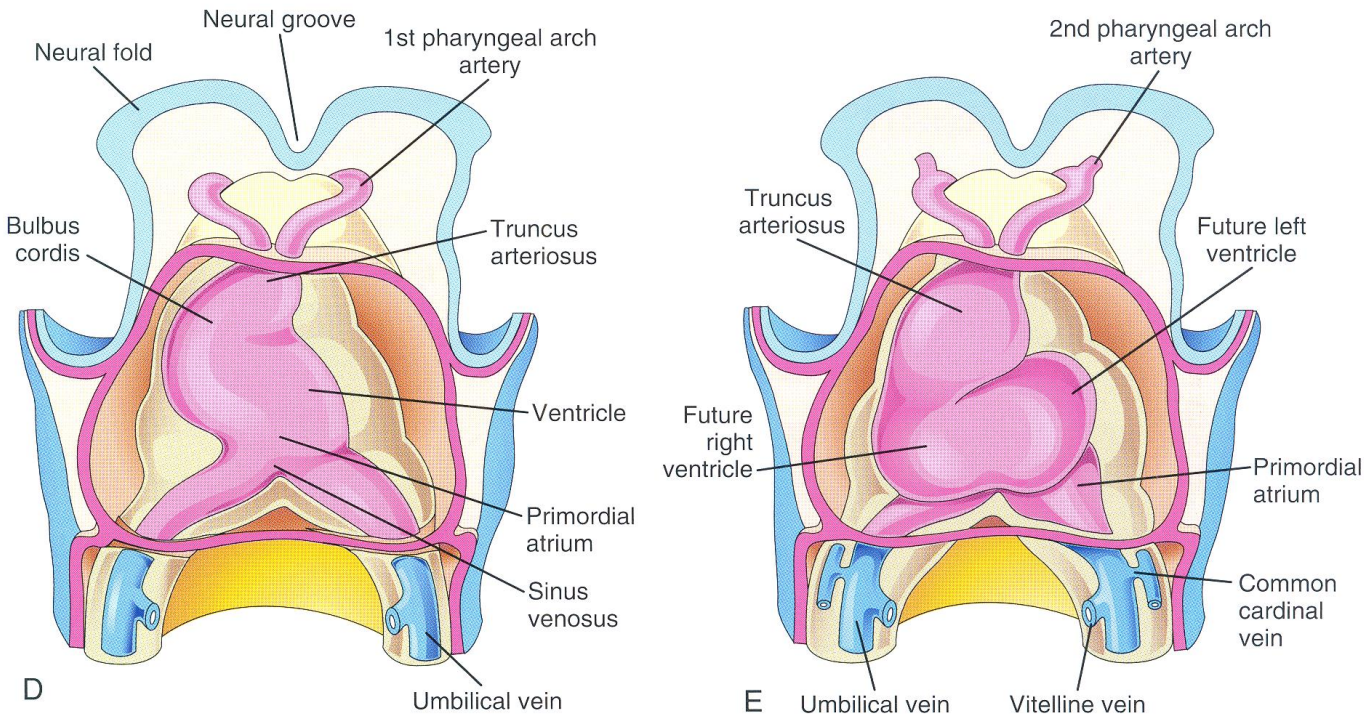
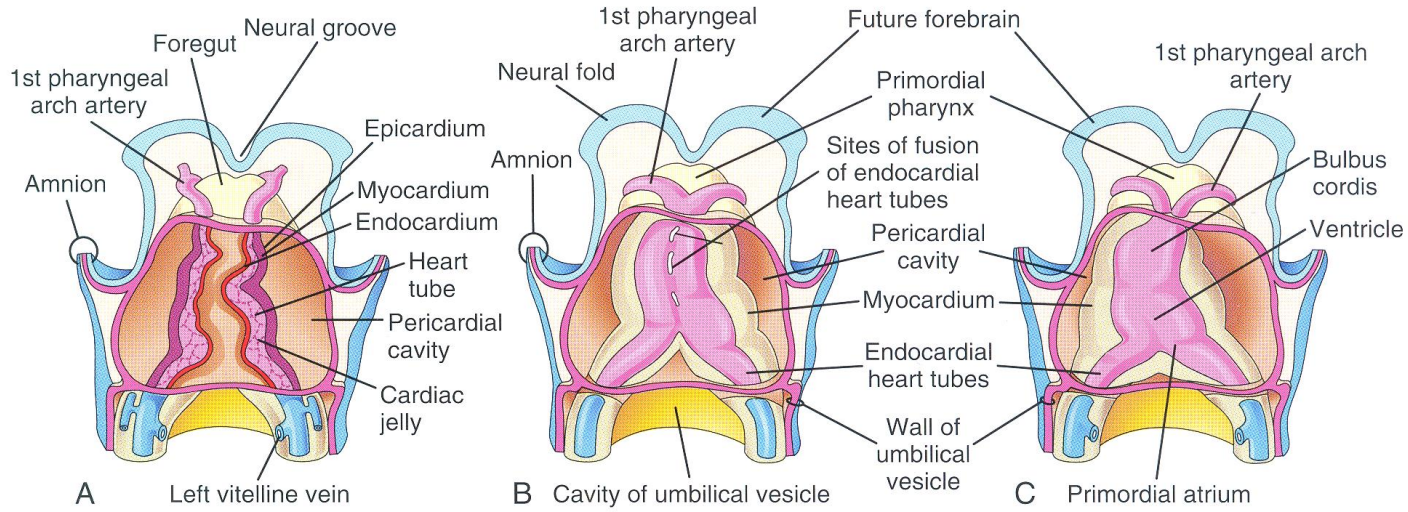


tubular heart is indeed a real structure

### Cor tubulare sigmoideum

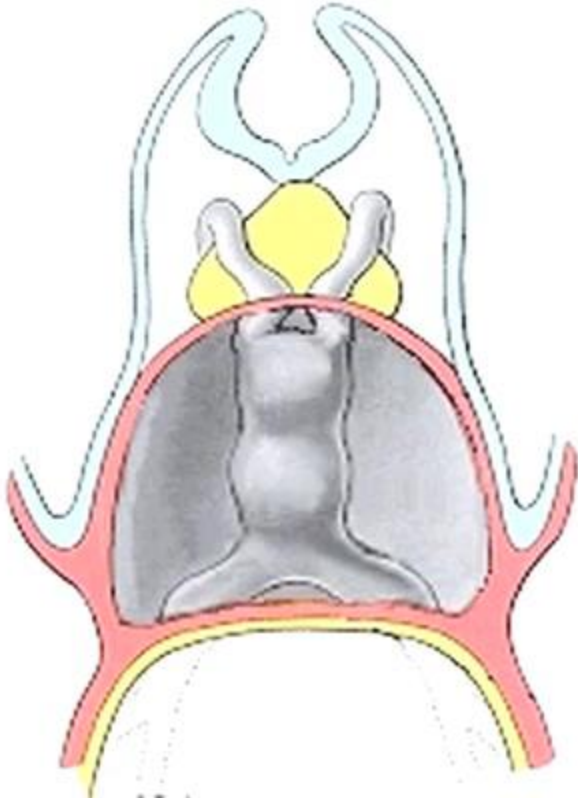


# DEVELOPMENT OF HEART



# DEVELOPMENT OF HEART

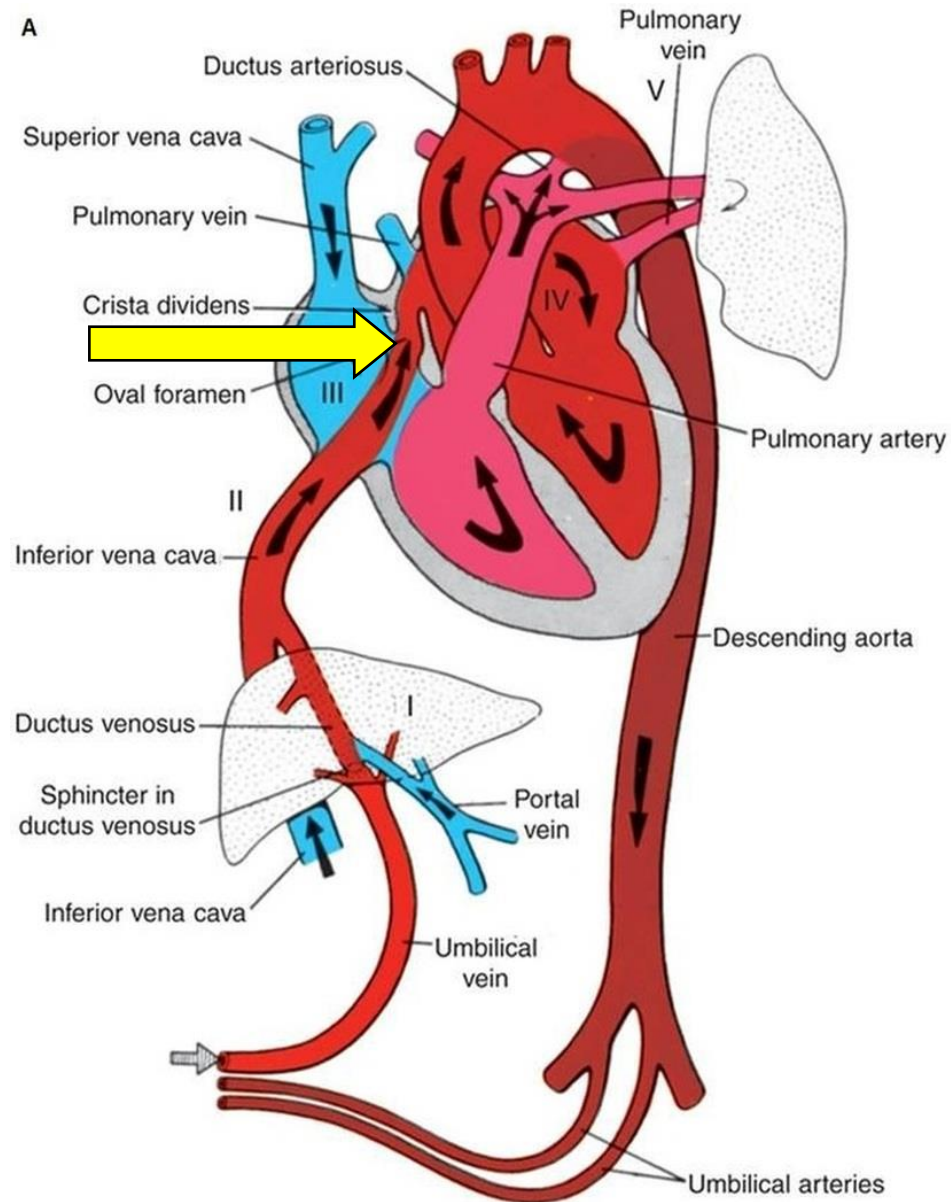
## Week 4



# DEVELOPMENT OF HEART

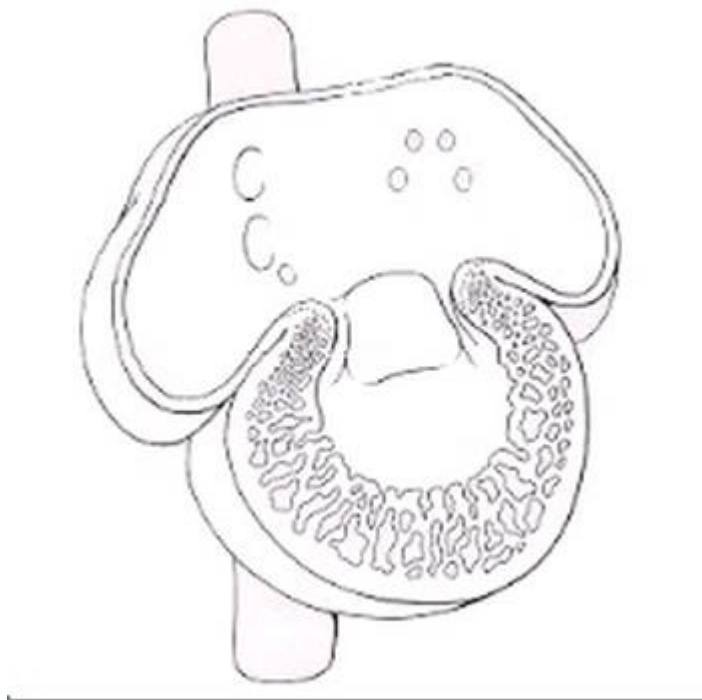
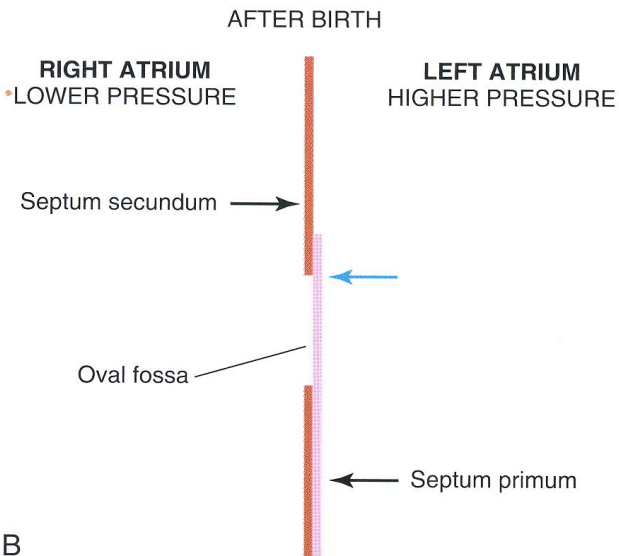
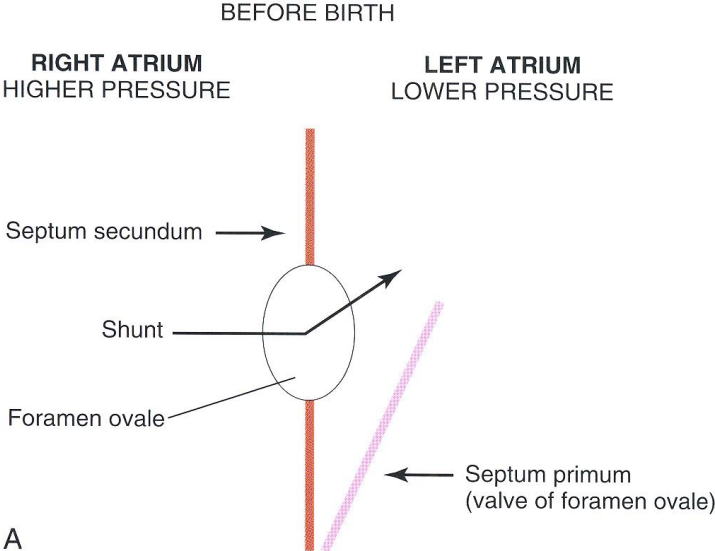
## Partitioning of atrium commune

- septum primum grows from dorso-cranial wall towards endocardial cushions
- incomplete closure → **foramen (ostium) primum**
- by apoptosis → **foramen secundum**
- **septum secundum** → surrounds **foramen ovale**
- valvula foraminis ovalis from septum primum
  
- foramen ovale: crucial embryonic shunt
- foramen ovale patens
  
- after atrial septation:
  - opening of sinus venosus shifts to the right
  - rest of sinus venosus → sinus coronarius



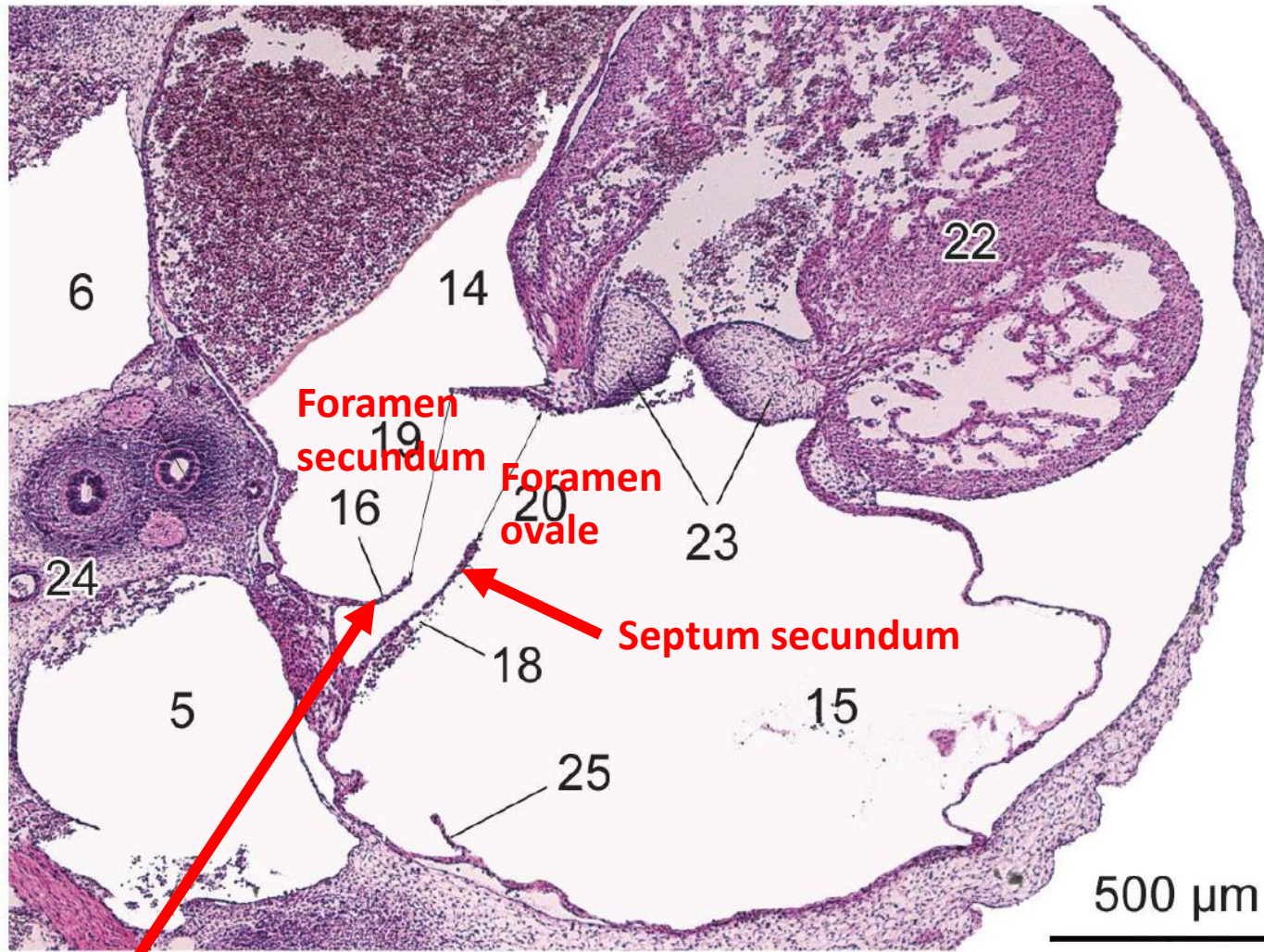


# DEVELOPMENT OF HEART



# DEVELOPMENT OF HEART

6. týden – 6<sup>th</sup> week

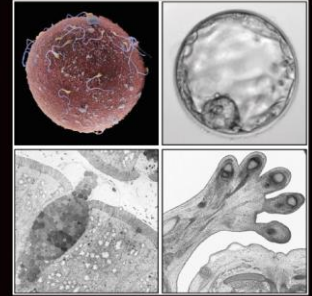


**Septum primum**

**Vývoj srdce – development of heart.** (1) perikardová dutina – pericardial cavity, (2) *bulbus cordis*, (3) *ventriculus primitivus*, (4) *atrium commune*, (5) *cornu dx. sinus venosus*, (6) *cornu sin. sinus venosus*, (7) *dorsal aortae*, (8) *truncus arteriosus*, (9) *conus cordis*, (10) základ pravé komory – developing right ventricle, (11) budoucí 1. faryngová arterie (aortální oblouk) – developing 1<sup>st</sup> pharyngeal artery (aortic arch), (12) *sulcus bulboventricularis*, (13) základ levé komory – developing left ventricle (14) *atrium sin.*, (15) *atrium dx.*, (16) *septum primum*, (17) *foramen (ostium) primum*, (18) *septum secundum*, (19) *foramen (ostium) secundum*, (20) *foramen ovale*, (21) *foramen interventriculare*, (22) *septum interventriculare*, (23) endokardové polštářky (návalky) – endocardial cushions, (24) *mediastinum*, (25) venózní chlopeč – venous valve.

MUNI  
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Cytologický a embryologický atlas  
Atlas of Cytology and Embryology



Petr Vaňhara • Jana Dumková

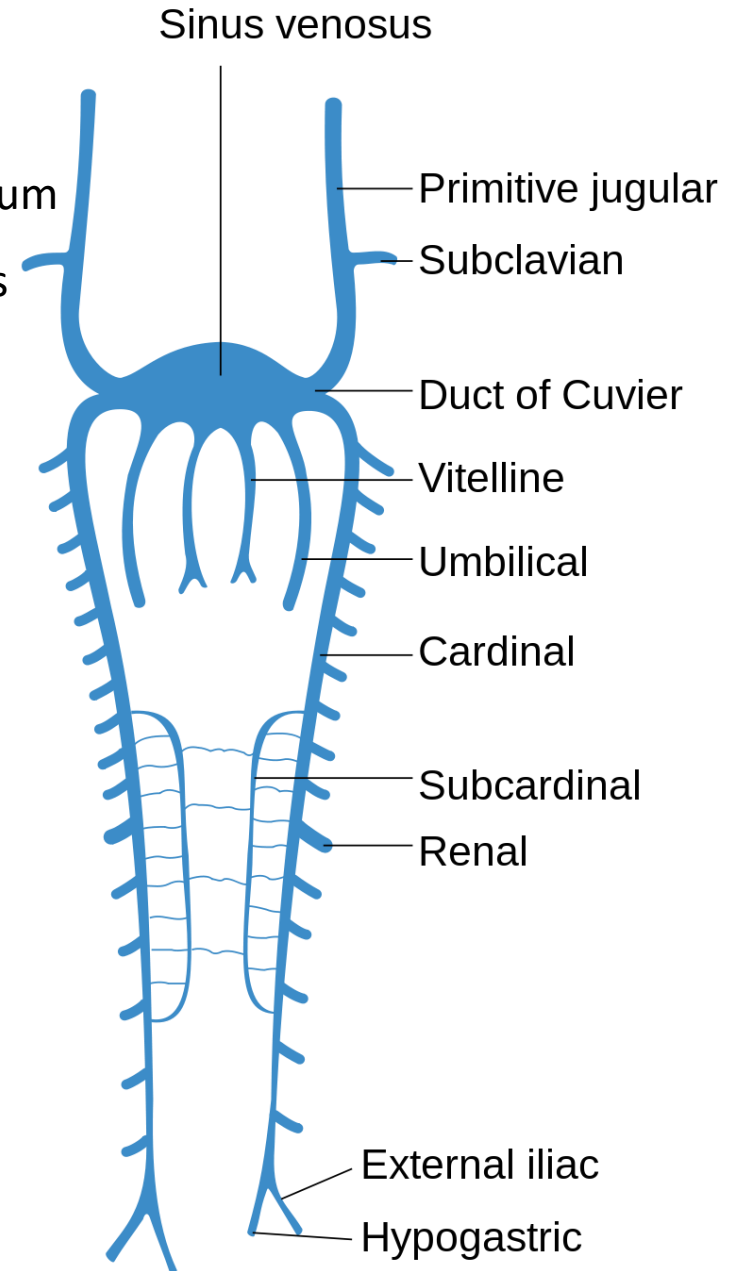
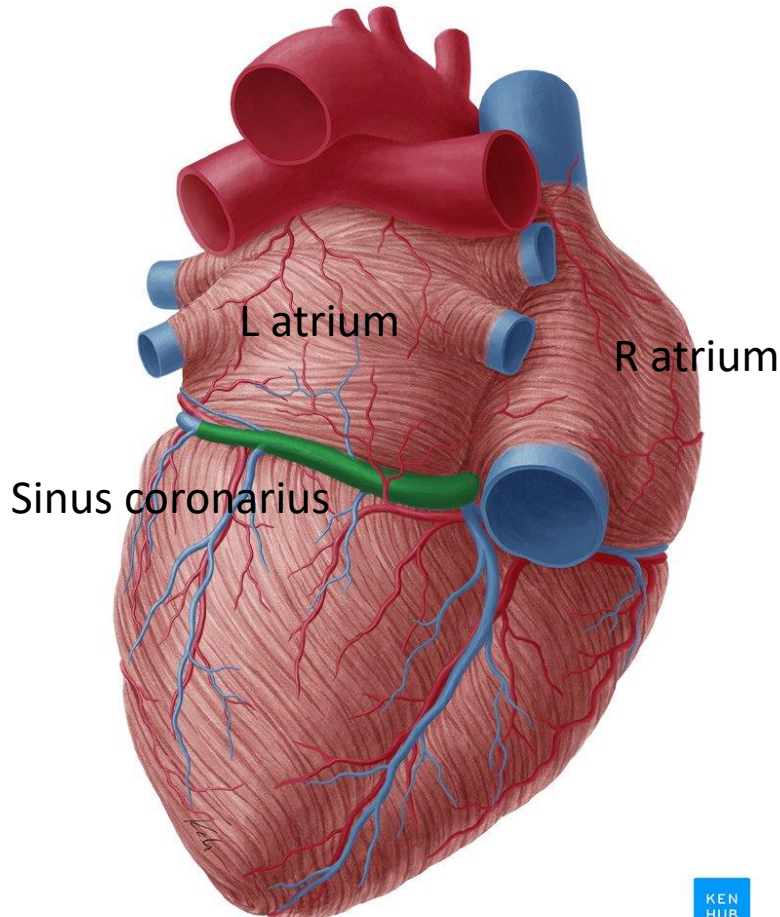
MASARYKOVA  
UNIVERZITA

Brno 2020

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# DEVELOPMENT OF HEART

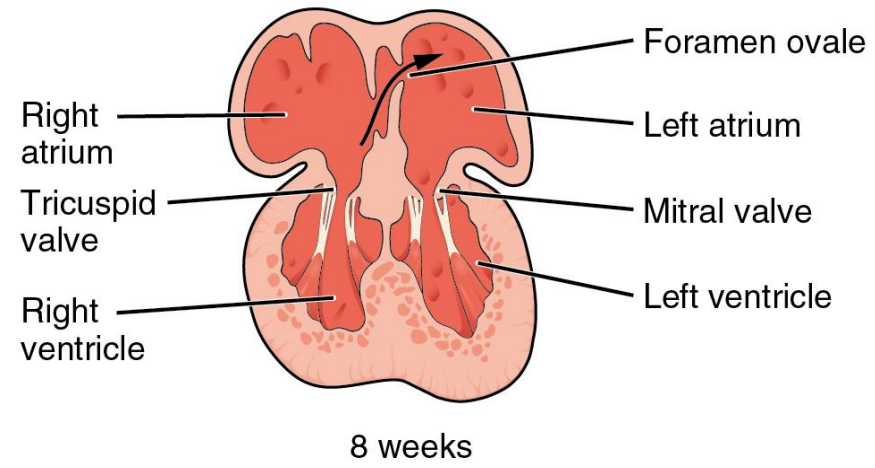
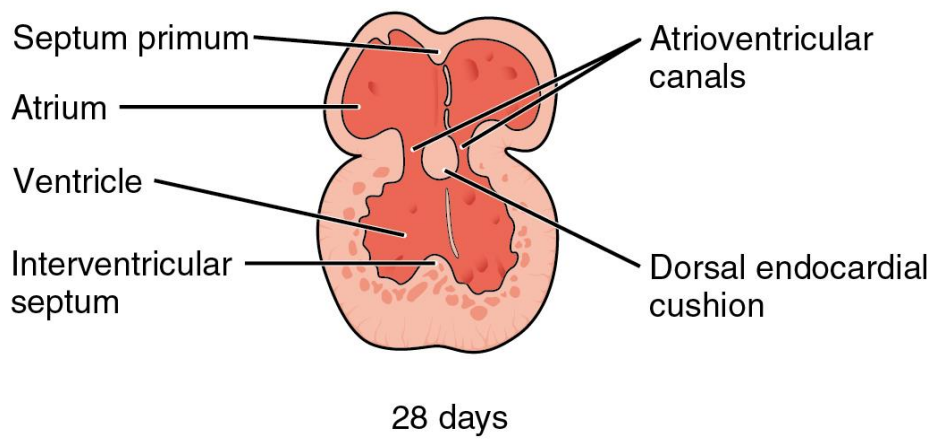
- **sinus venosus** during atrial septation:
  - shift of sinus venosus opening to the right → right atrium
  - left part sinus venosus is separated → sinus coronarius



# DEVELOPMENT OF HEART

## Partitioning of ventriculus communis

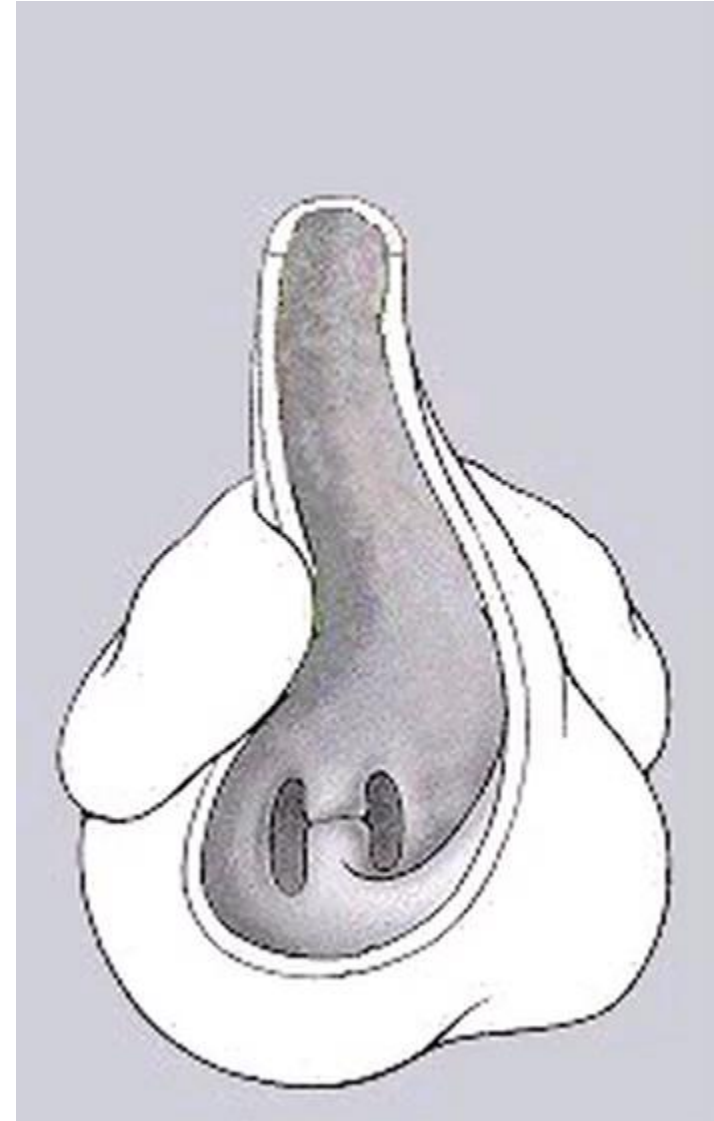
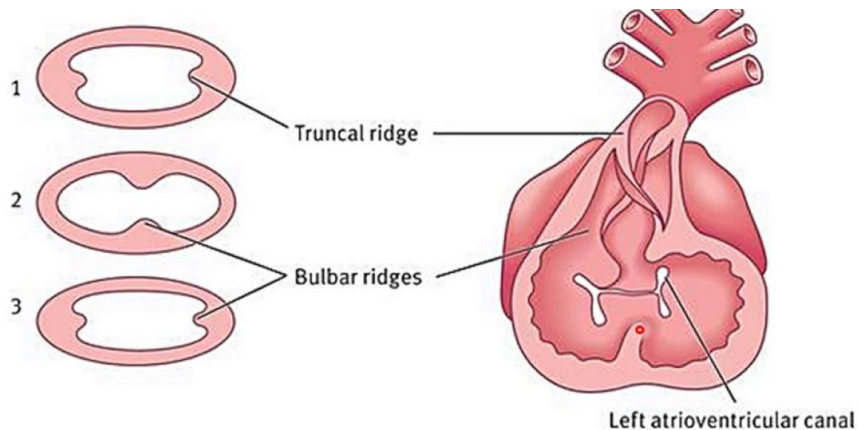
- septum interventriculorum primitivum – temporary
- septum interventriculare at the end of week 4 – grows cranially
- foramen interventricualre – closure linked to development of aortico-pulmonary septum
- pars membranacea (septi interventricularis)
- pars muscularis (septi interventricularis) - medial walls of both ventricles



# DEVELOPMENT OF HEART

- **Partitioning of bulbus cordis and truncus arteriosus**

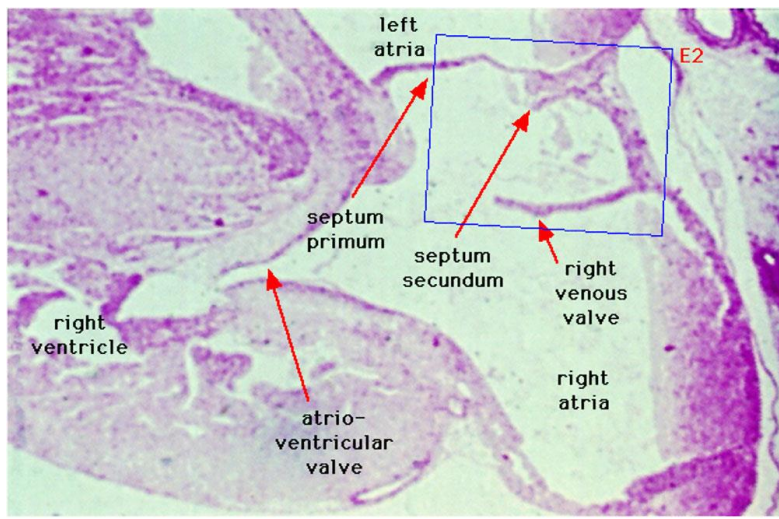
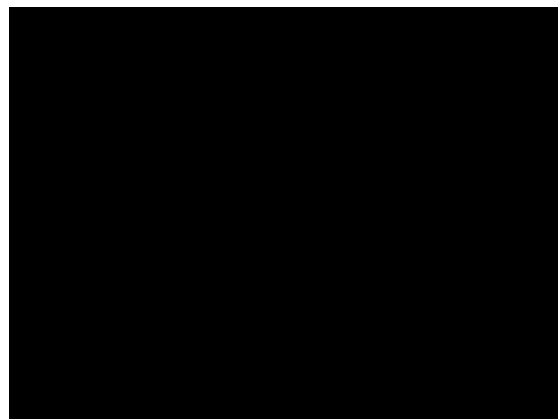
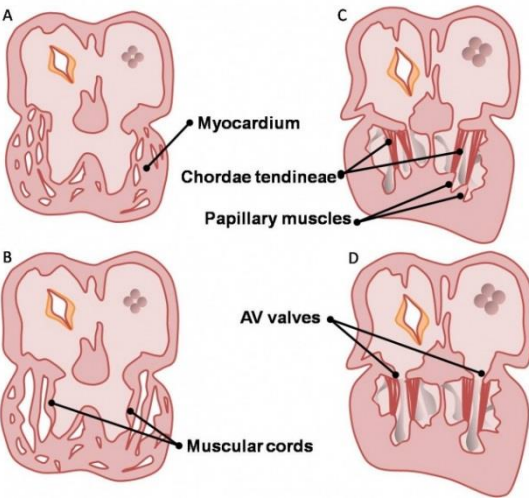
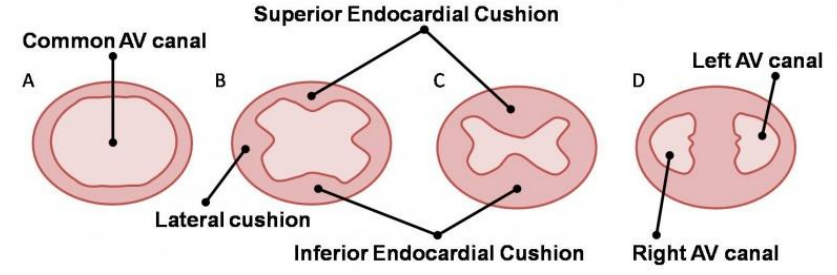
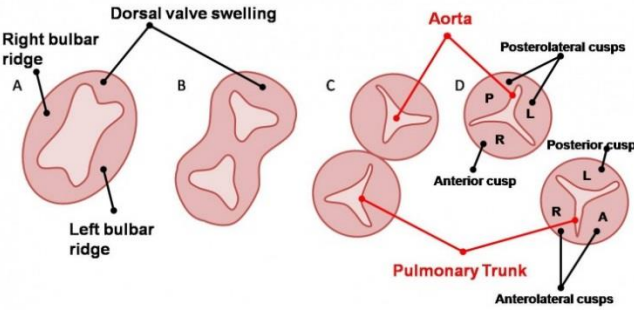
- 5<sup>th</sup> week – ridges in bulbus and truncus from neural-crest mesenchyme
- 180° spiraling – spiral aortico-pulmonary septum
- pulmonary trunk twists around aorta
- bulbus cordis is embedded into the definitive ventricles:
  - right ventricle: conus arteriosus (infundibulum) → pulmonary trunk
  - left ventricle: aortic vestibule



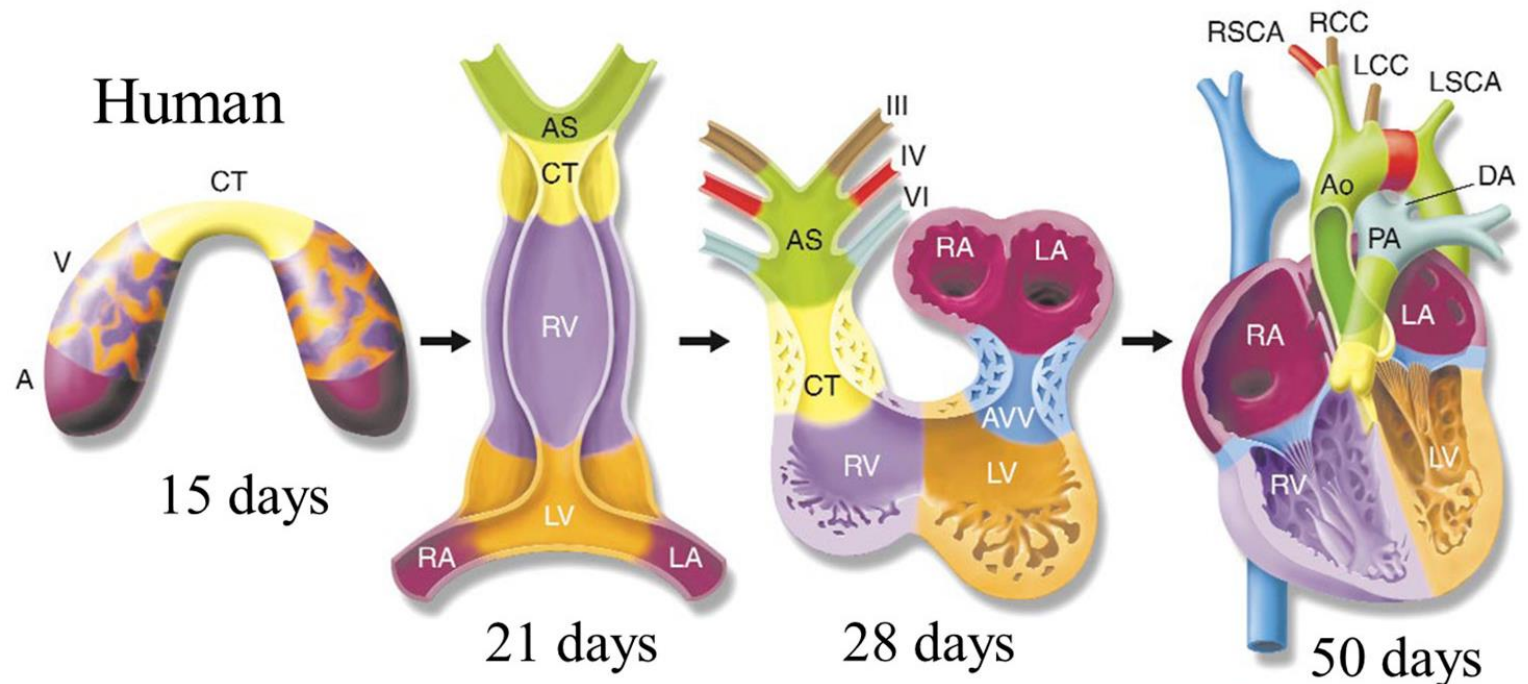
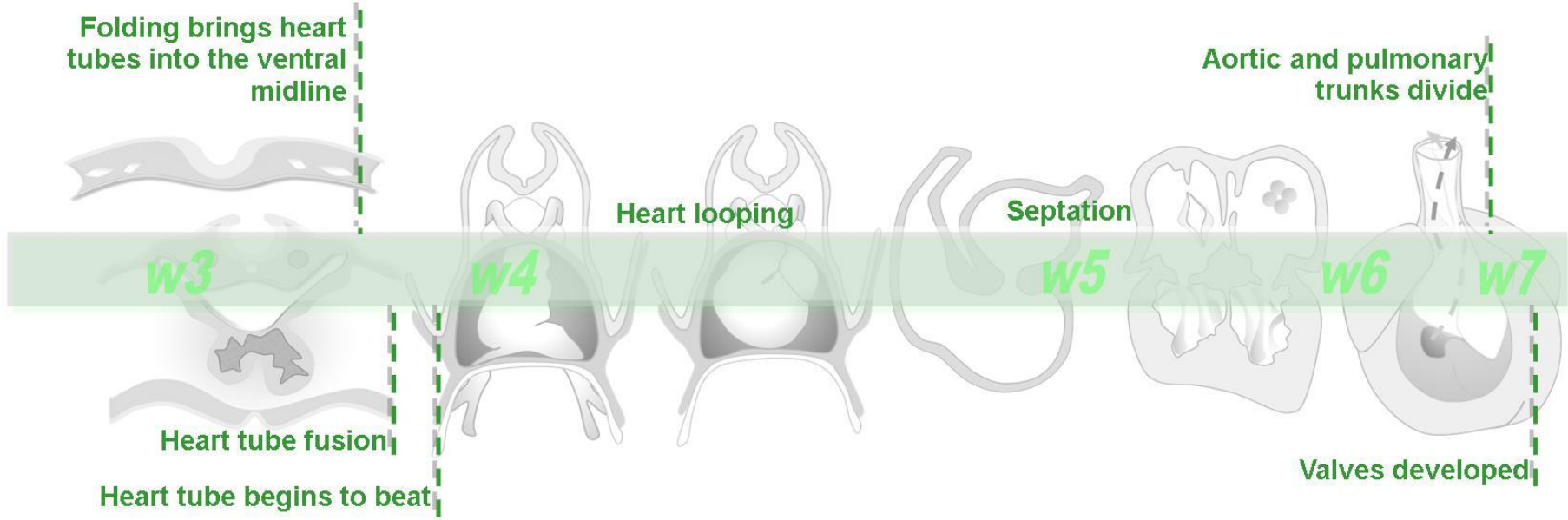
# DEVELOPMENT OF HEART

- Development of cardiac valves**

- semilunar valves** develop by the partitioning of truncus arteriosus from three swellings of endocardial tissue
- neural crest origin
- AV valves** (tricuspid and mitral) develop similarly at AV canals



# DEVELOPMENT OF CARDIOVASCULAR SYSTEM

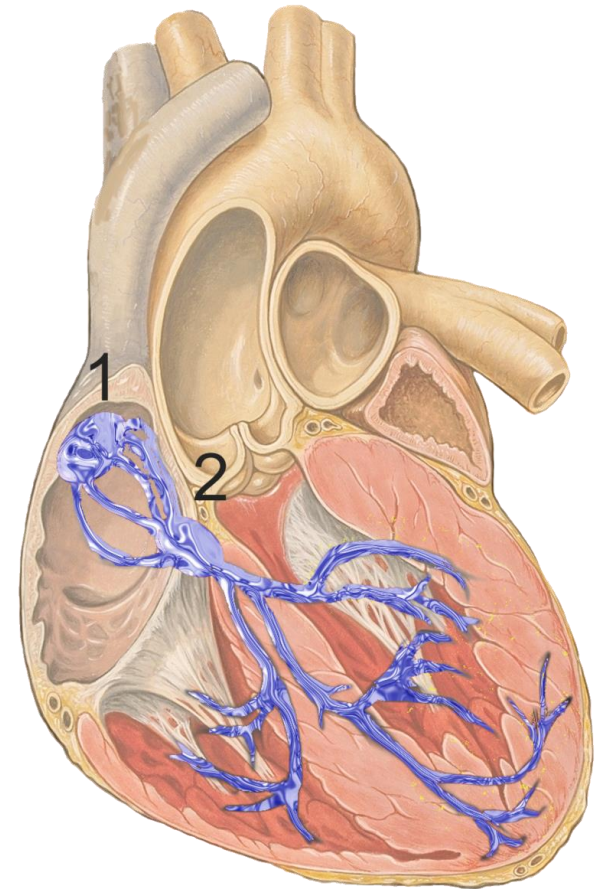
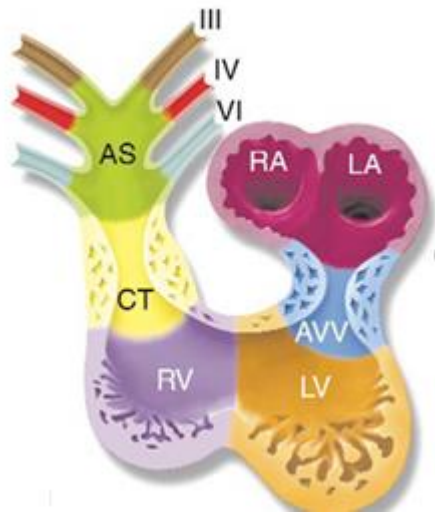


# DEVELOPMENT OF HEART

## Development of conductive heart system

Definitive conductive heart system provides the electrical conduction between atria and ventricles

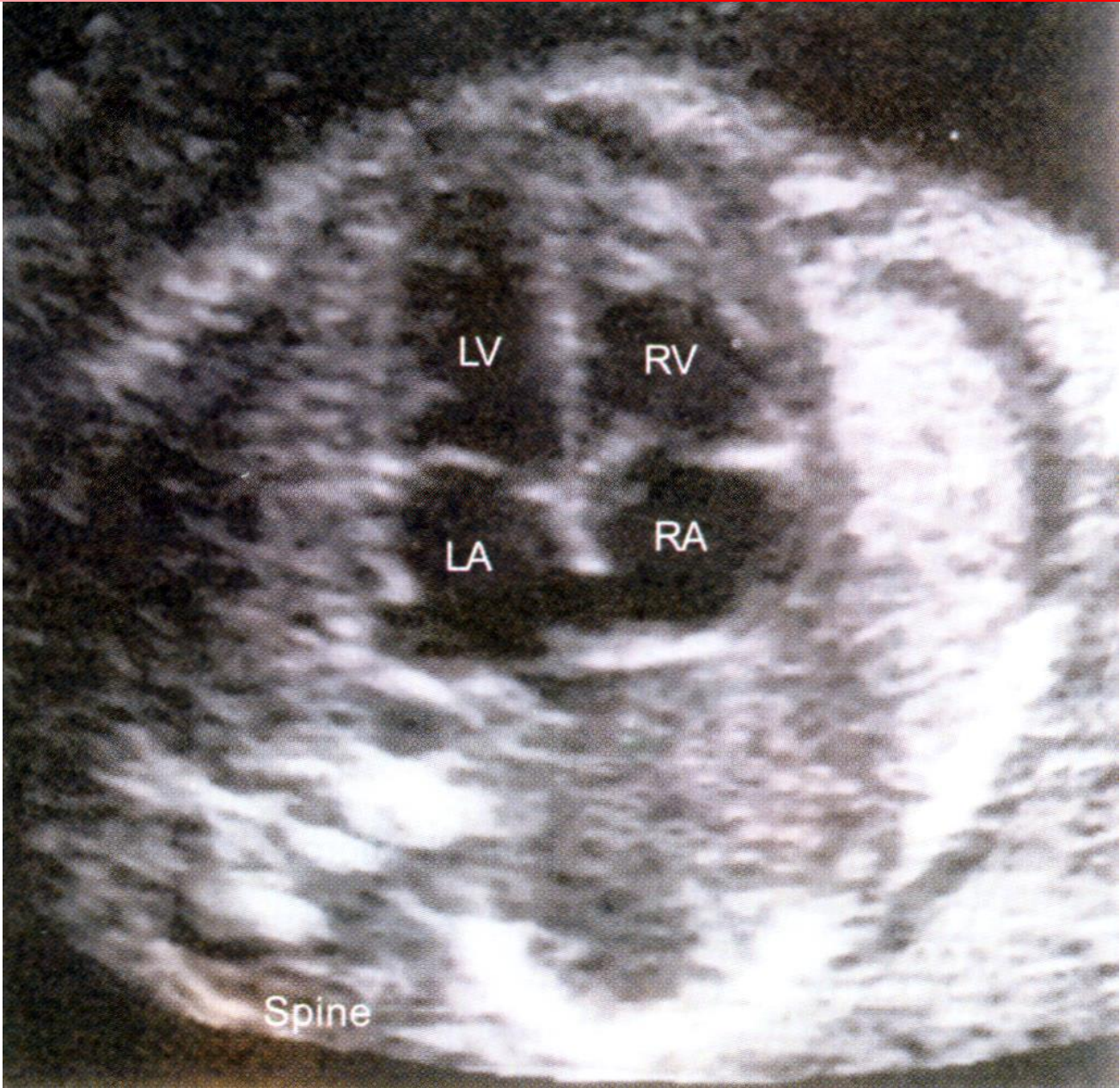
- First are all muscle layers connected
- Primitive atrium – primary pacemaker
- SA node in 5th weeks from tissues of sinus venosus
- Cells of interatrial and atrioventricular septa contribute to formation of AV node and fasciculus atrioventricularis → bundle branches → ventricular myocardium





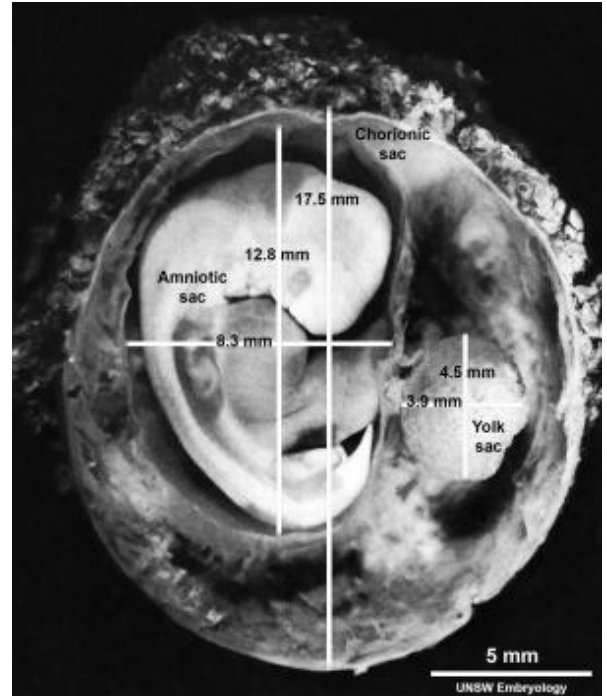
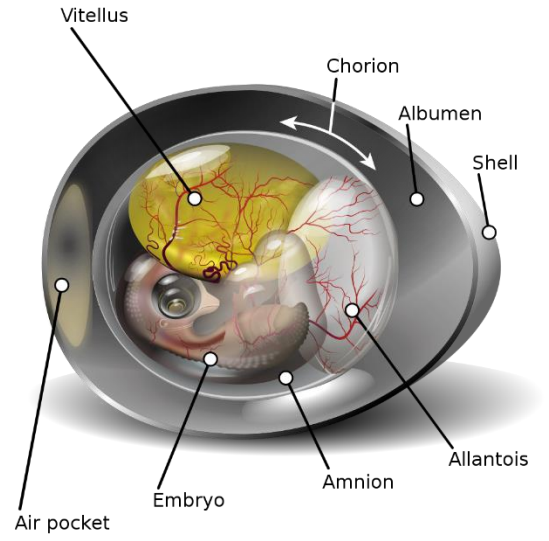
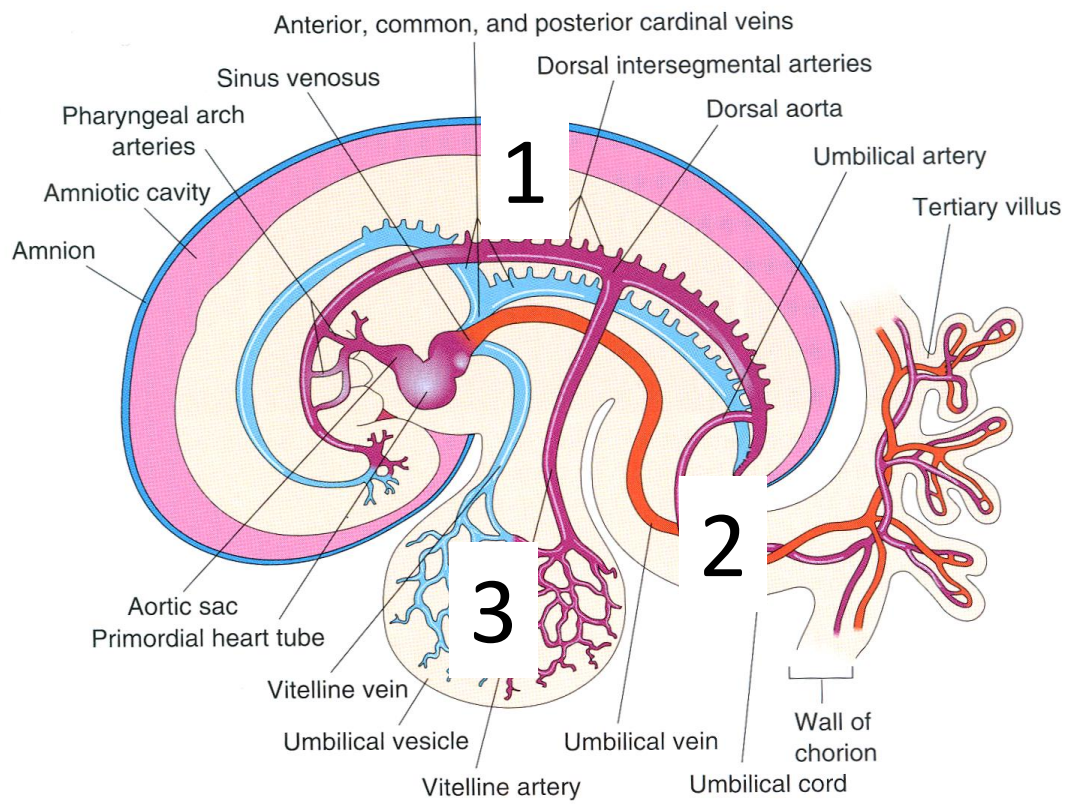
# DEVELOPMENT OF HEART

Week 20



# DEVELOPMENT OF CARDIOVASCULAR SYSTEM

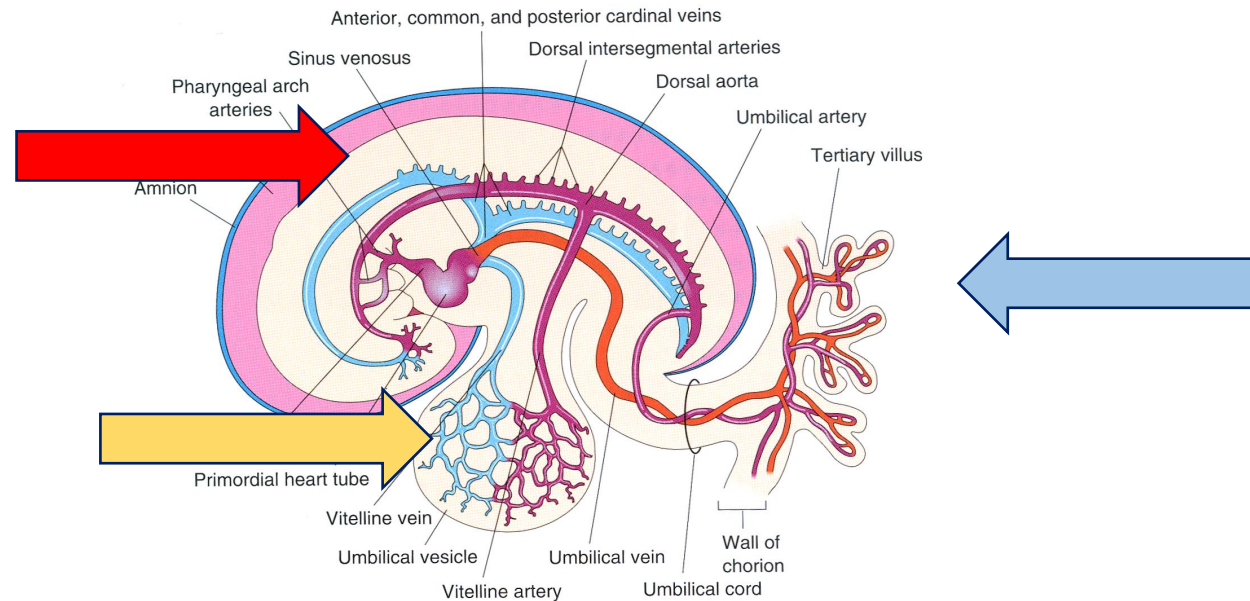
## Week 4



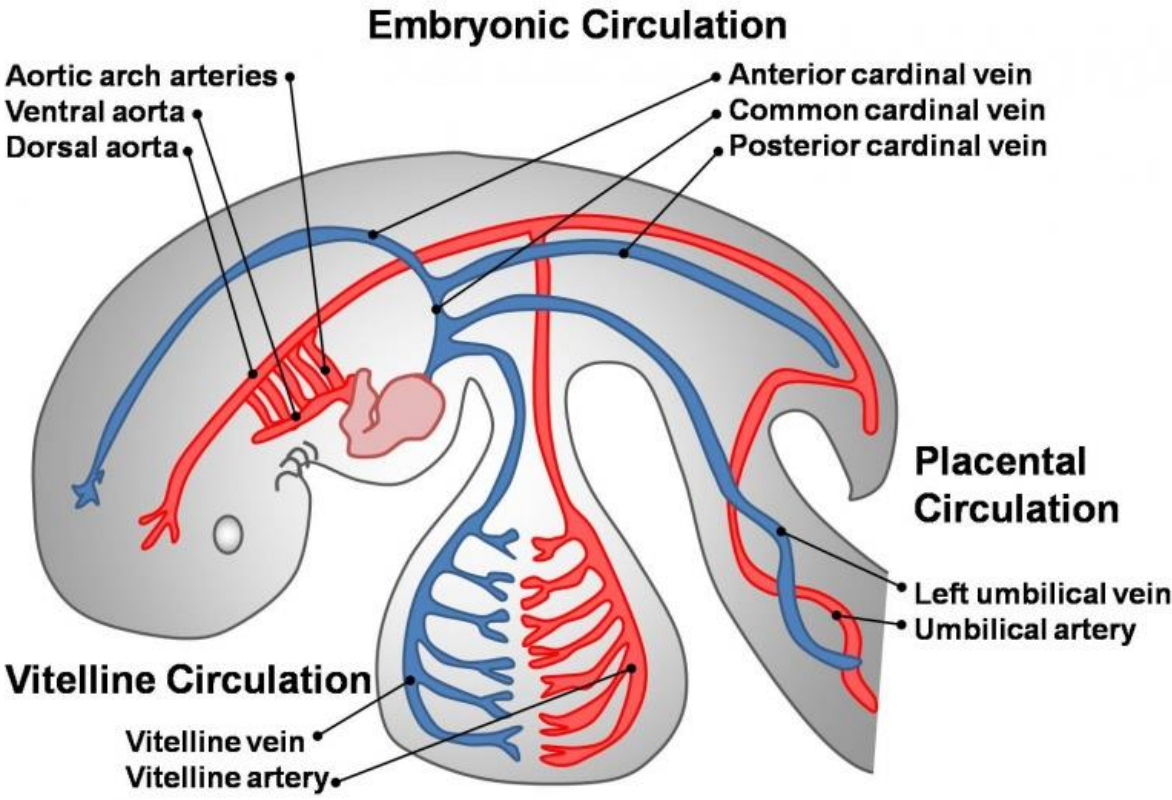
# DEVELOPMENT OF CARDIOVASCULAR SYSTEM

## Week 4

- embryonic circulation:** heart tube → *truncus arteriosus* → aortal arches → paired dorsal aorta → caudally fuse into single aorta dorsalis → capillary beds → paired cardinal veins (drain pre- and postcardinal veins) → *ductus Cuvieri* → *sinus venosus*
- vitelline circulation:** dorsal aorta → *aa. omphalomesentericae* → fuse into single *a. omphalomesenterica* → *vv. omphalomesentericae* + *vv. umbilicales* → paired *truncus vitelloumbilicalis* → *sinus venosus*
- umbilical circulation:** dorsal aorta → *aa. umbilicales* → chorion → *vv. umbilicales* + *vv. omphalomesentericae* → paired *truncus vitelloumbilicalis* → *sinus venosus*



# Arteries



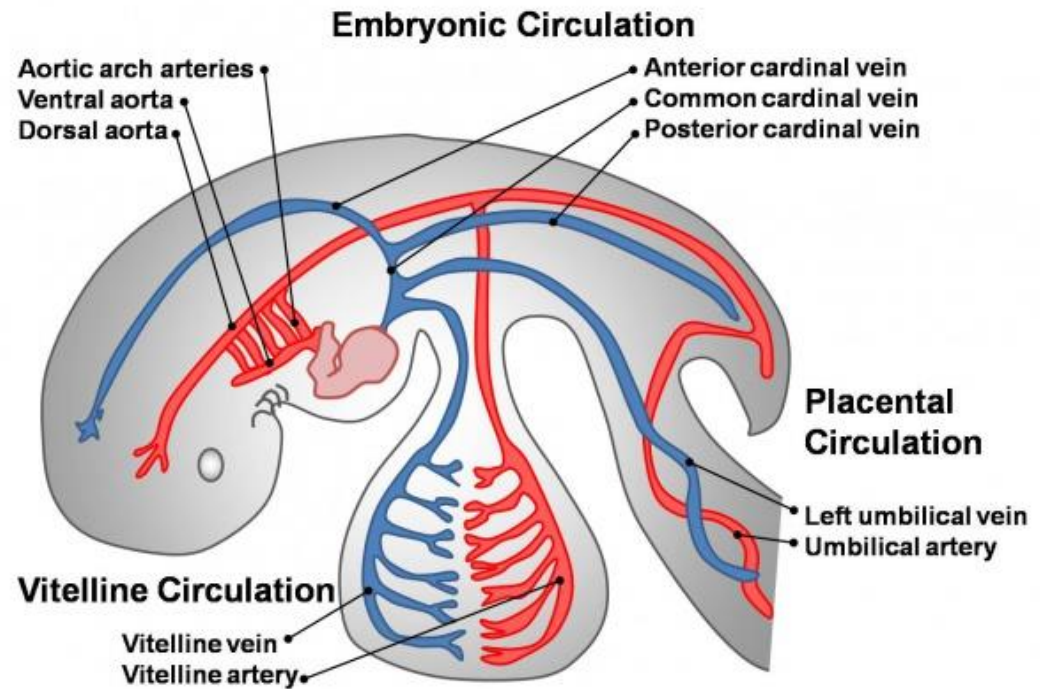
# DEVELOPMENT OF ARTERIES

## Dorsal aorta

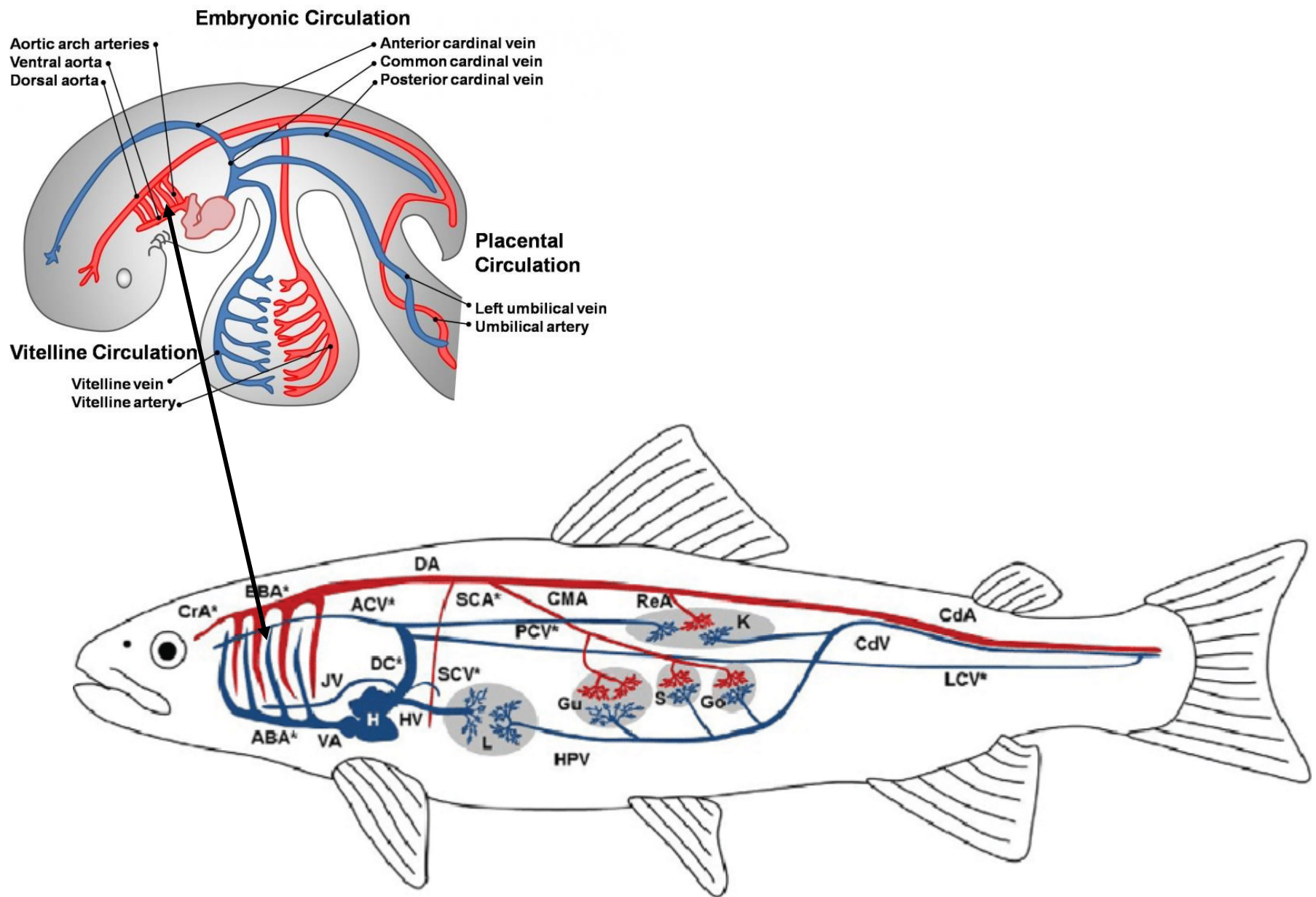
- originally a paired structure - fusion into a single dorsal aorta → a. descendens
- aortal arches

## Ventral aorta

- originally a paired structure
- fusion into the aortic cas when embryo folds

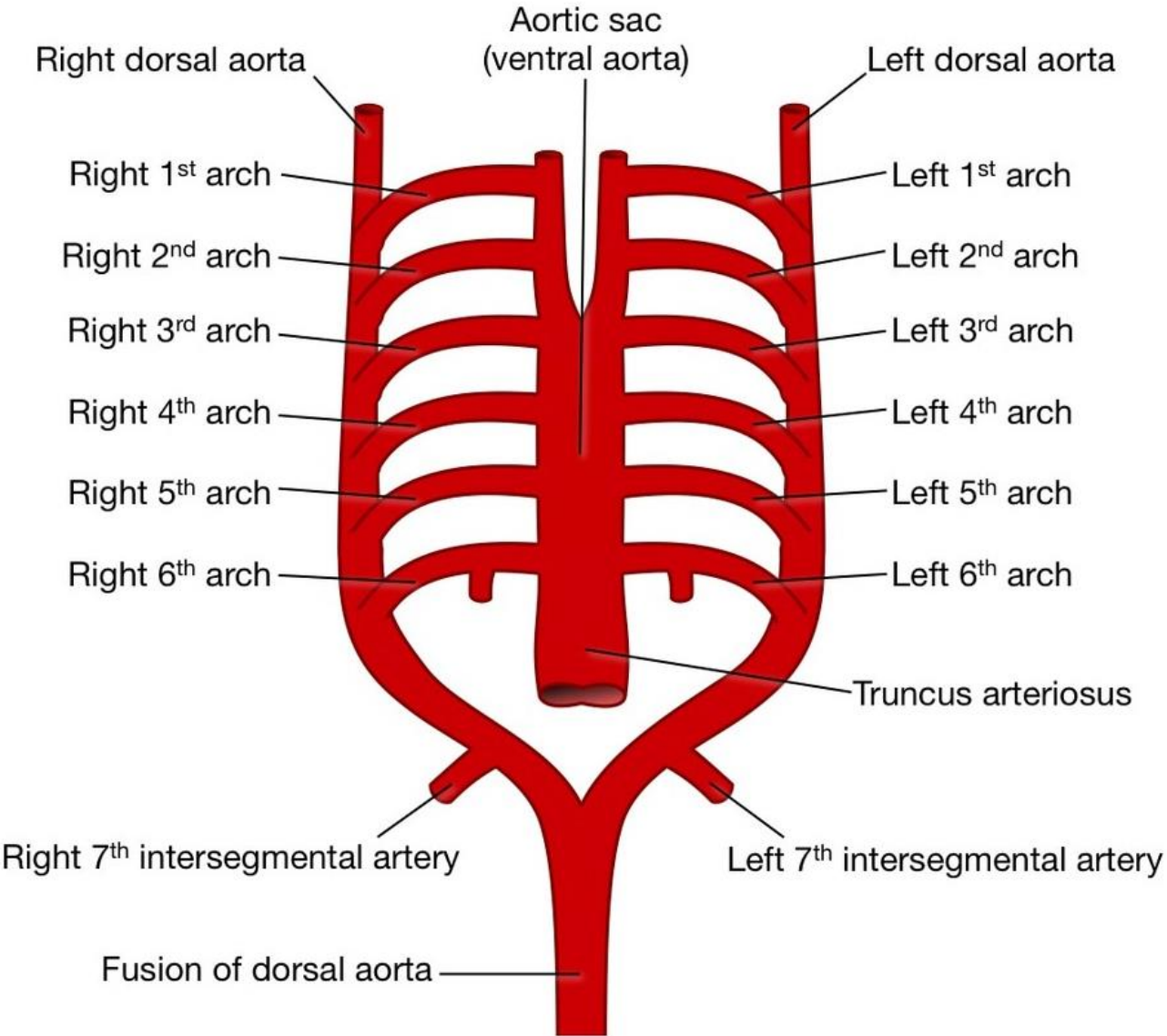


# DEVELOPMENT OF ARTERIES



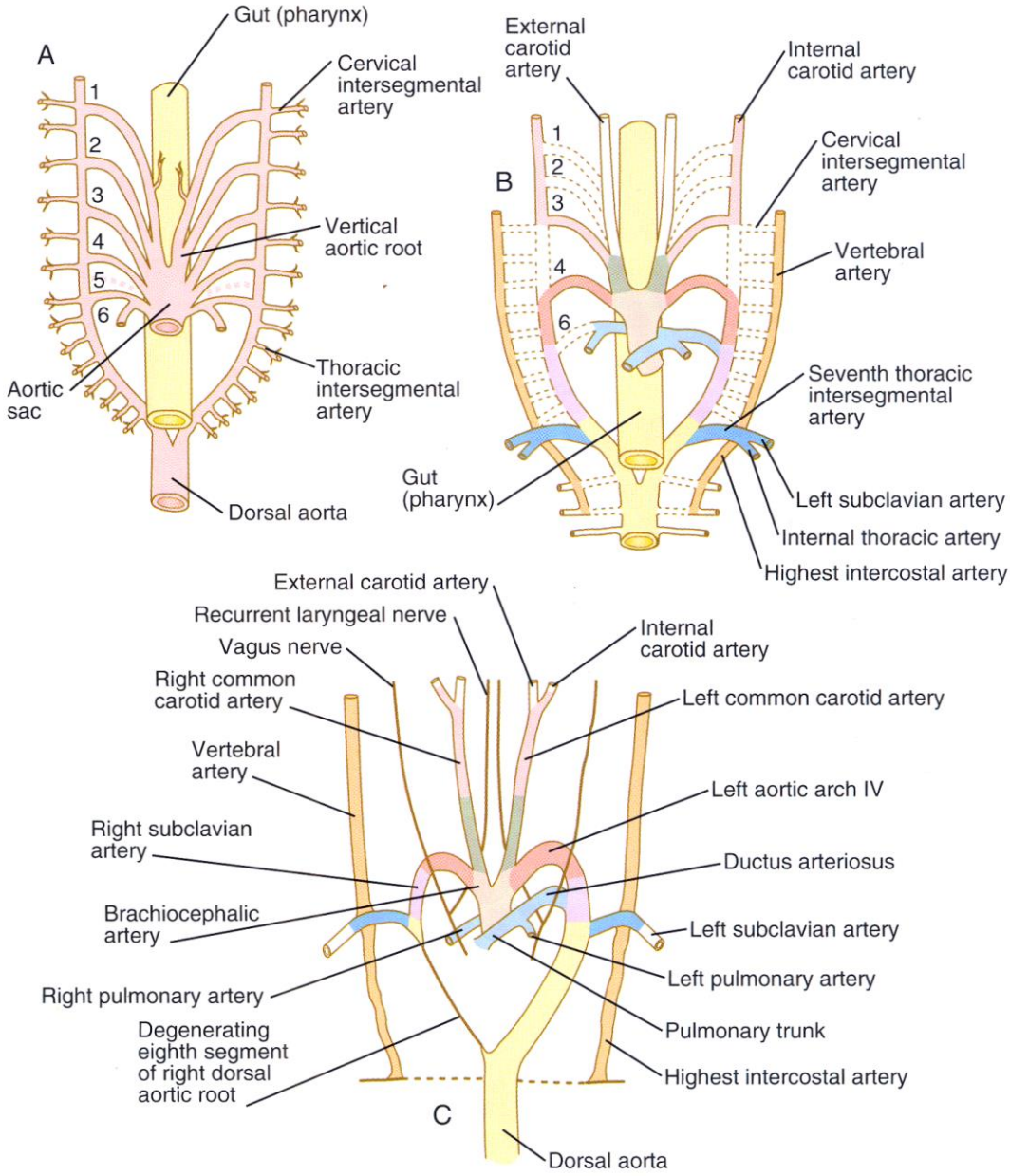
# DEVELOPMENT OF ARTERIES

## Development of large arteries – aortic arches



# DEVELOPMENT OF ARTERIES

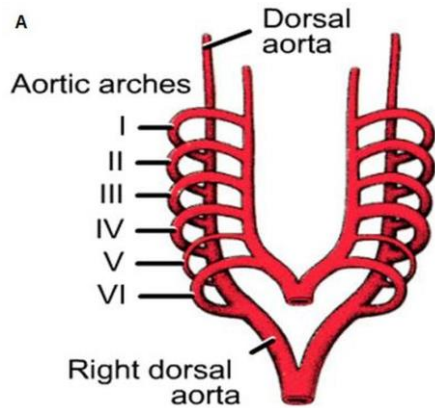
## Arctic arches



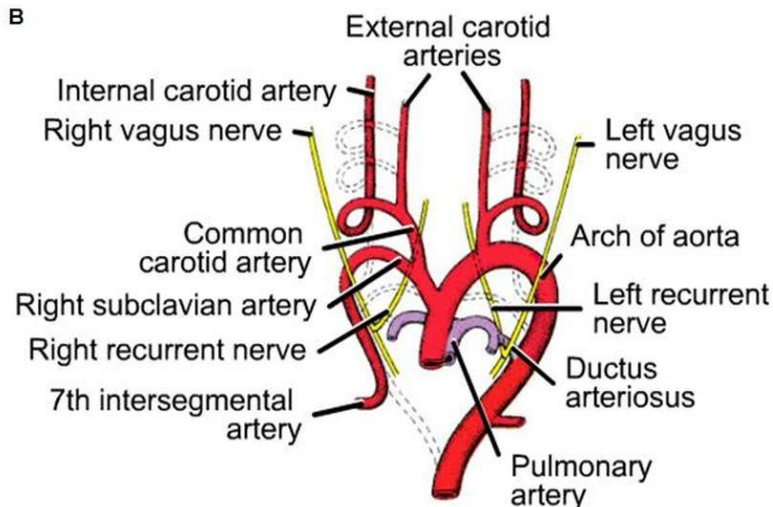


# DEVELOPMENT OF ARTERIES

## Aortic arches

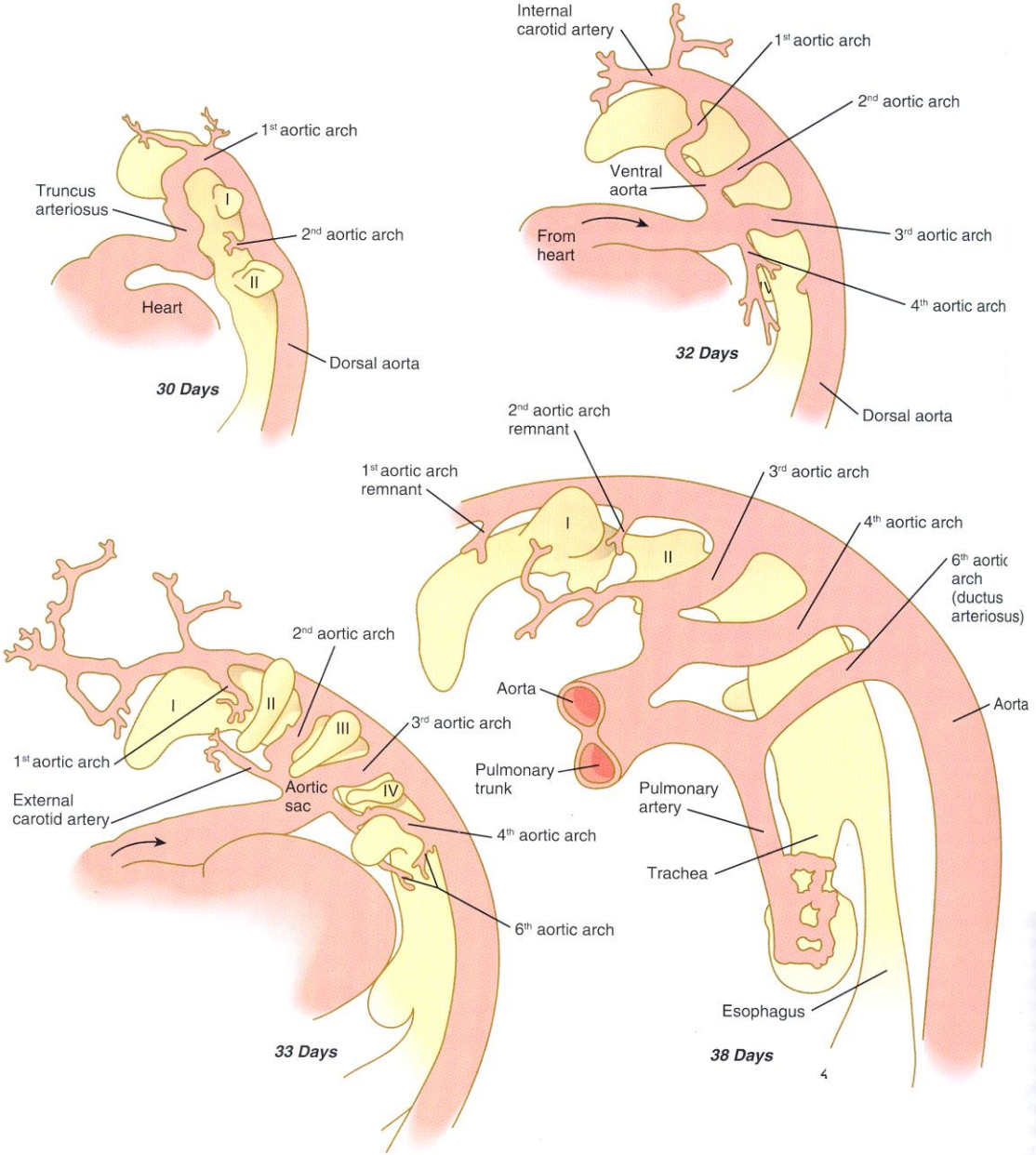


- 1 mostly disappears, **a. maxillaris**
- 2 mostly disappears, **a. stapedia** and **a. hyoidea**
- 3 proximal parts **aa. carotides communes**, distal parts of **aa. carotides internae**
- 4 right: proximal part of **a. subclavia dextra** (distal part from dorsal aorta and 7<sup>th</sup> intersegmental artery);  
left: **arcus aortae** (aorta develops from aortic sac and left dorsal aorta)
- 5 does not develop or quickly degenerates
- 6 right: from proximal part: **a. pulmonalis dextra**, distal part disappears  
left: from proximal part: **a. pulmonalis sinistra**, from distal part: **ductus arteriosus**.



# DEVELOPMENT OF ARTERIES

## Aortic arches



# DEVELOPMENT OF ARTERIES

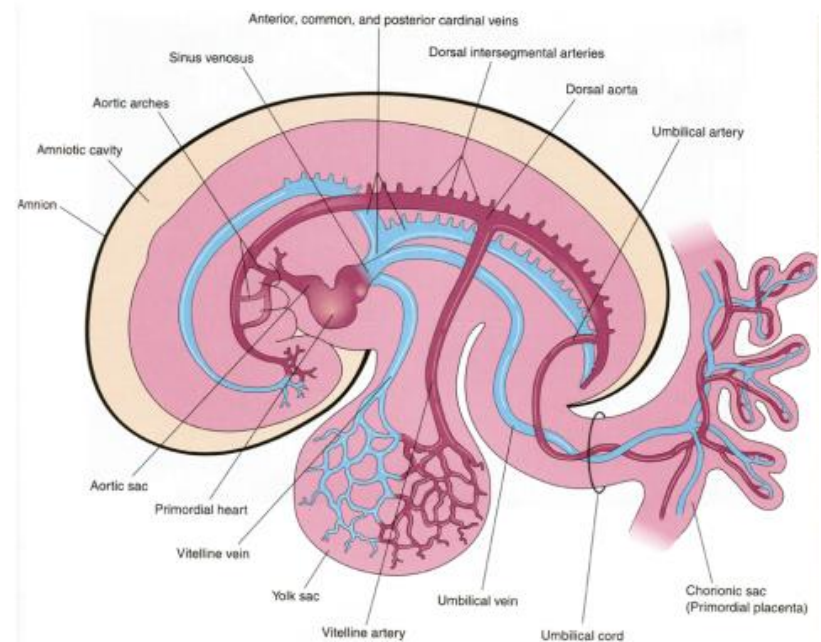
## Branches of dorsal aorta

- **intersegmental arteries** (parietal, dorsal) a **visceral** (ventral, towards primitive gut)



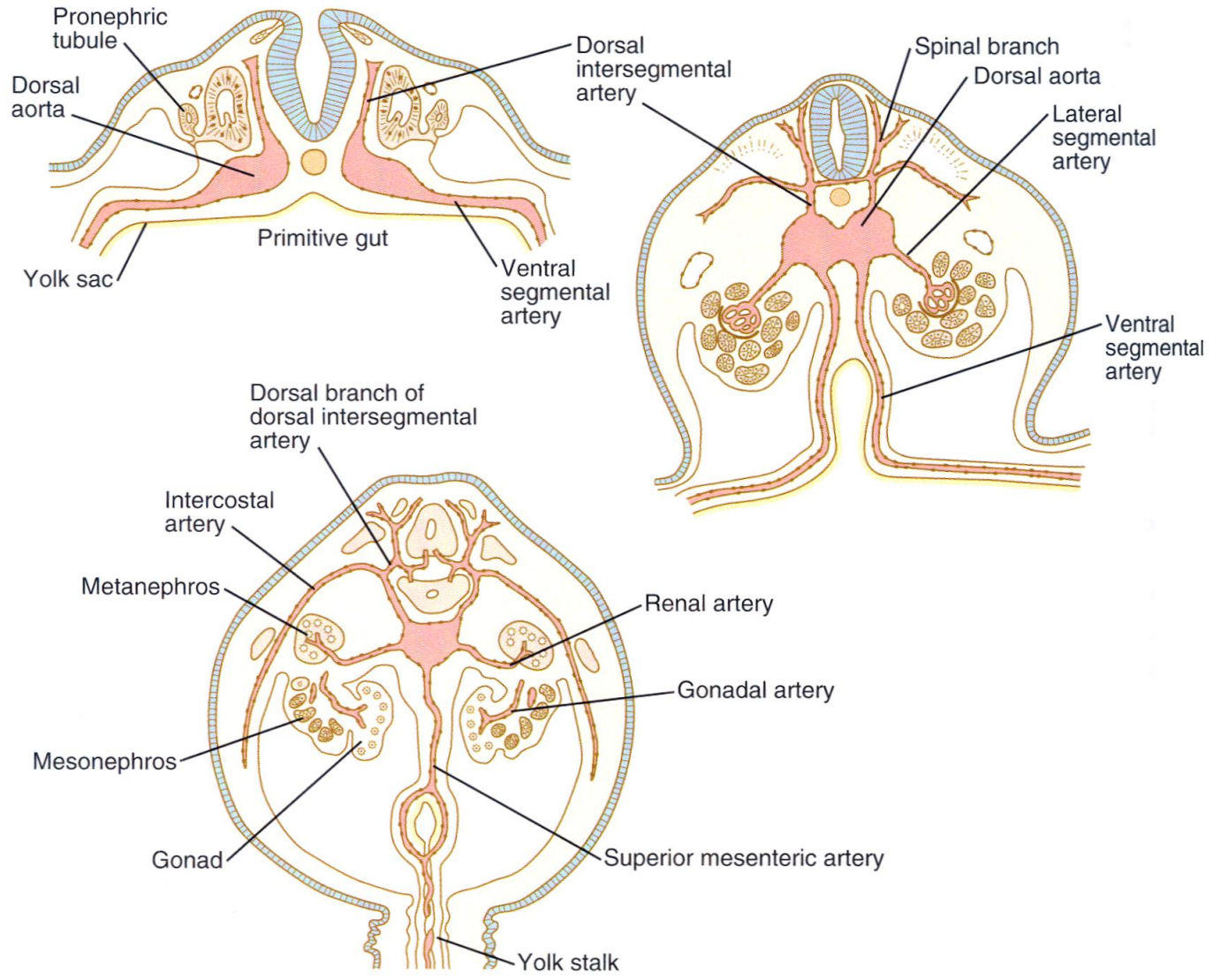
truncus coeliacus  
a. mesenterica superior  
a. mesenterica inferior

- between somites
- vascularisation of somites and their derivatives
- intersegmental arteries:
  - neck → a. vertebralis
  - chest → aa. intercostales
  - abdomen → aa. lumbales
  - sacral → aa. sacrales laterales
- part of 7<sup>th</sup> intersegmental artery → a. subclavia dx.
- caudal end of dorsal aorta → a. sacralis media



# DEVELOPMENT OF ARTERIES

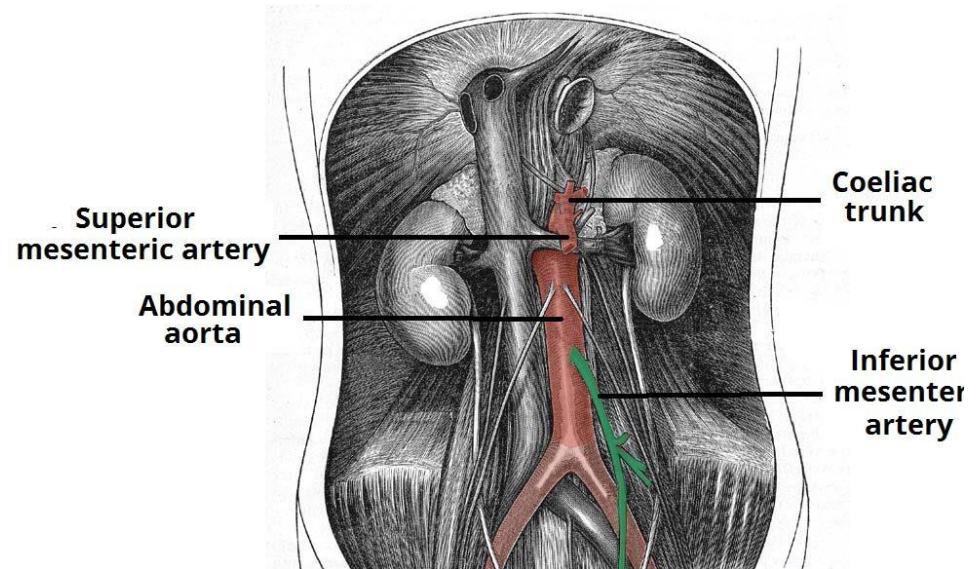
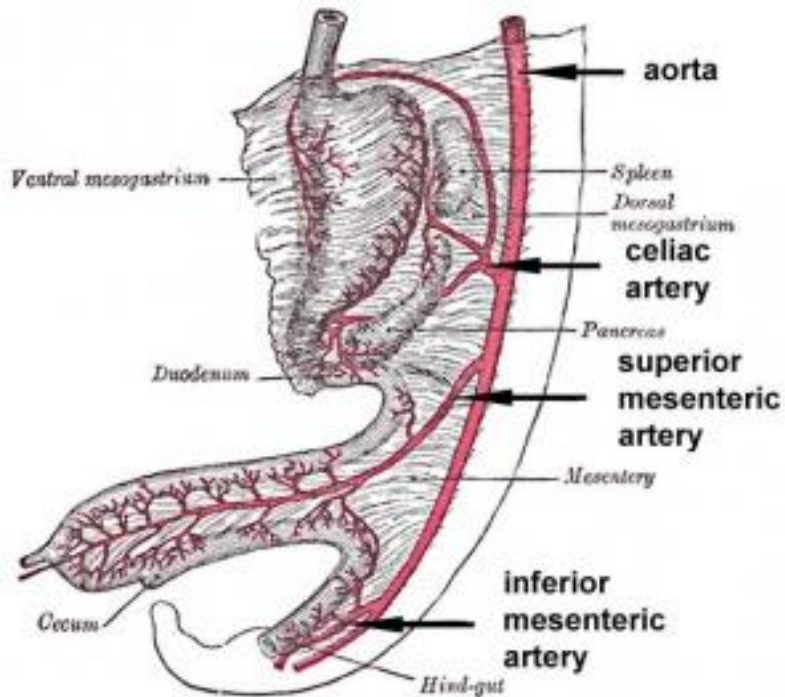
## Intersegmental arteries



# DEVELOPMENT OF ARTERIES

## Vitelline arteries

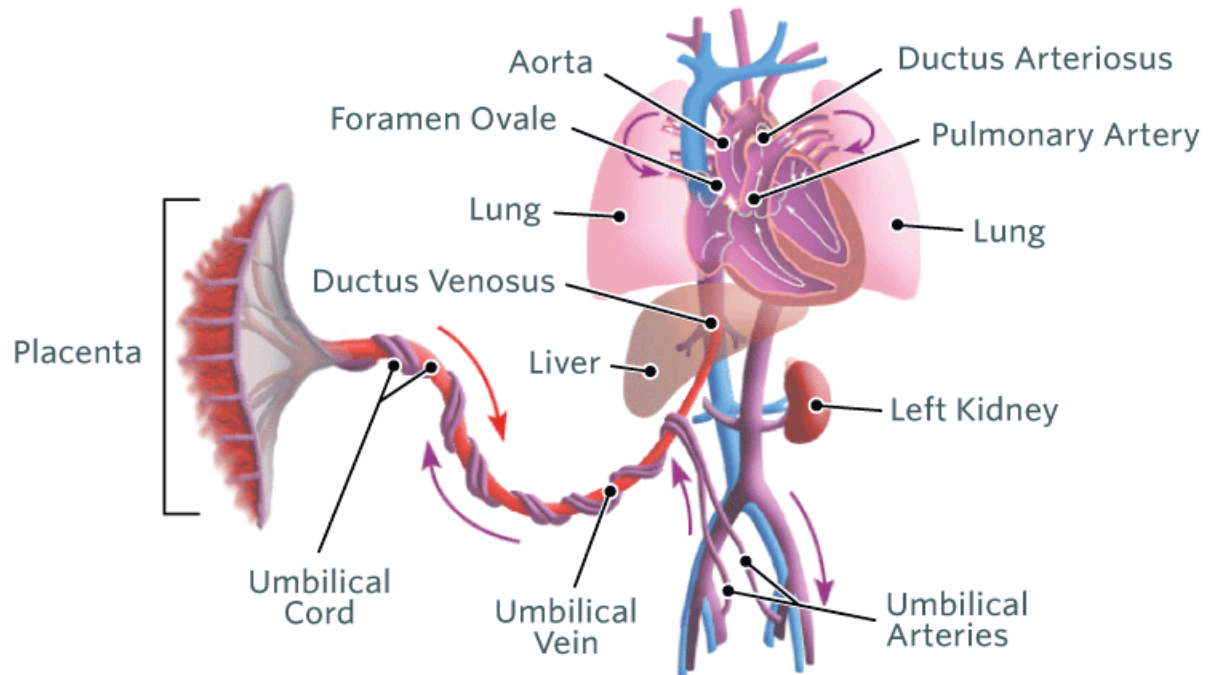
- ventral branches of dorsal aorta
- aa. vitellinae (aa. omphalomesentericae) reduced to three principal vessels:
  - 1 **truncus coeliacus**
  - 2 **a. mesenterica superior**
  - 3 **a. mesentrica inferior**



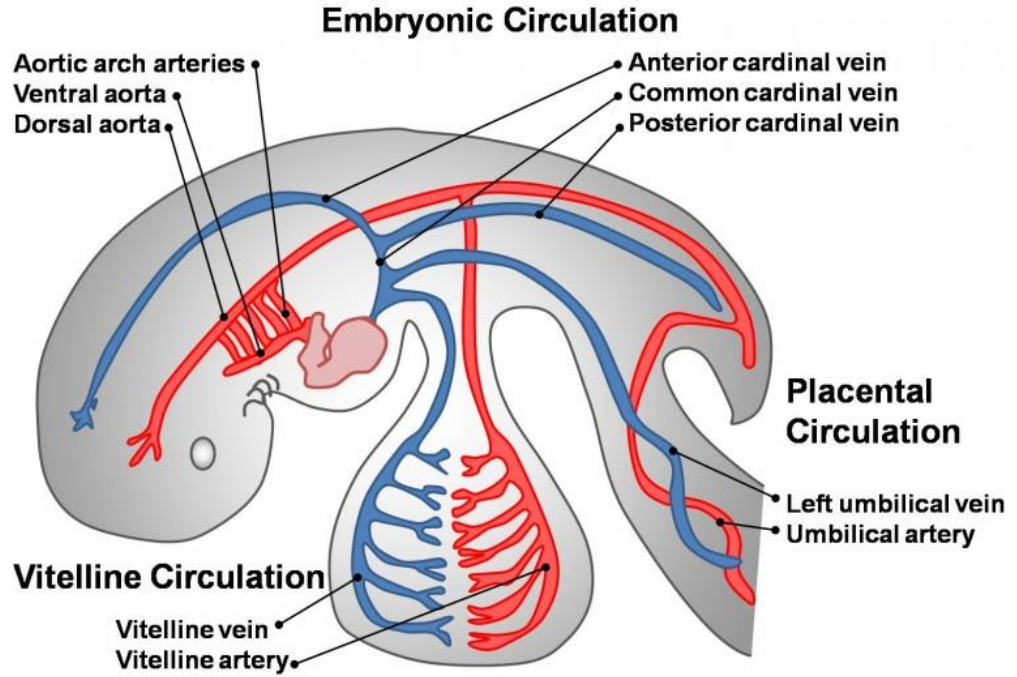
# DEVELOPMENT OF ARTERIES

## Umbilical arteries

- First, aa. umbilicales are ventral branches of dorsal aorta
- Later, aa. umbilicales are continuations to aa. iliacae communes and aa. communes internae.
- Abnormally, a single a. umbilicalis develop (can result in growth retardation of fetus)
- After birth: proximal parts of aa. umbilicales form aa. iliacae internae and aa. vesicales superiores. Distal parts obliterate.



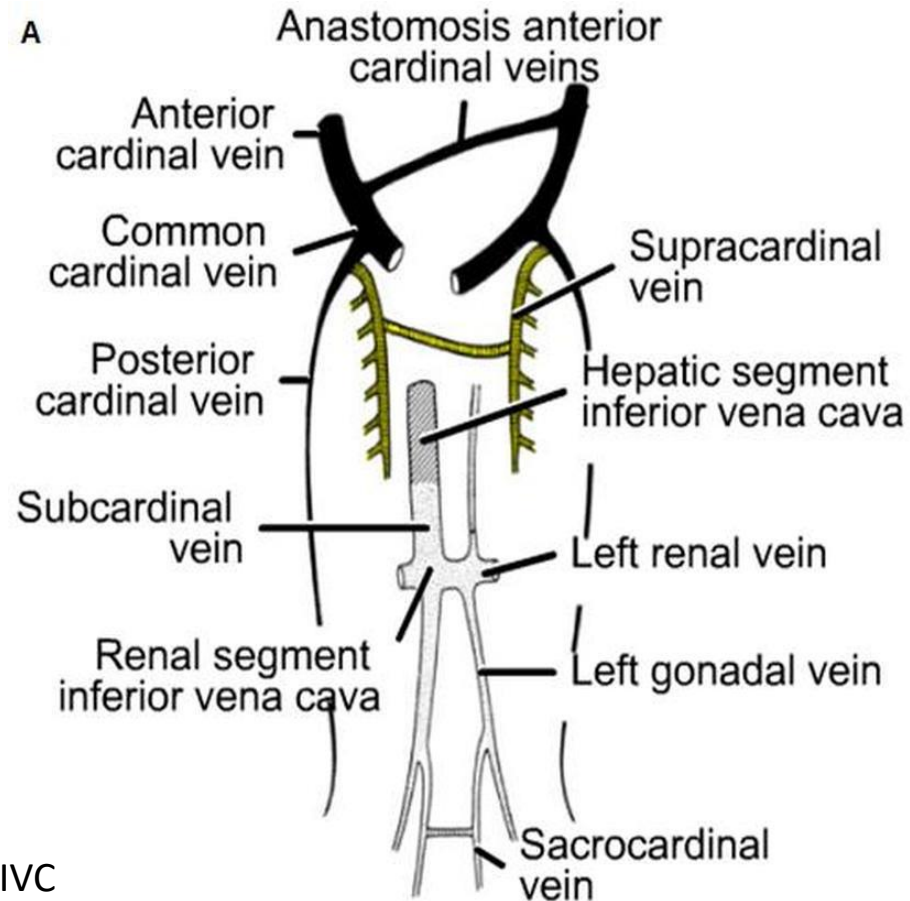
# Veins



# DEVELOPMENT OF VEINS

## Cardinal veins

- main venous system of embryo
- v. cardinales anteriores et posteriores,  
→ v. cardinales communes
- paired v. cardinales anteriores
- 8th week: anastomosis (L→R)
  - → v. brachiocephalica
  - caudal part of left v. card. ant. disappears
  - right v. card. ant. + v. card. commun.: SVC
- paired v. cardinales posteriores
  - primary vessels of mesonephros
  - persists as branches of v. hemiazygos and v. azygos
  - replaced by subcardinal and supracardinal veins
- paired v. subcardinales
  - anastomoses also to v. cardinales posteriores
  - left: v. renalis, v. suprarenales, gonád veins, part of IVC
- paired v. supracardinales
  - cranial – anastomosis – v. azygos et v. hemiazygos
  - caudal left v. supracardinalis disappears, right – lower part of IVC (anastomosis to v. subcardinalis)





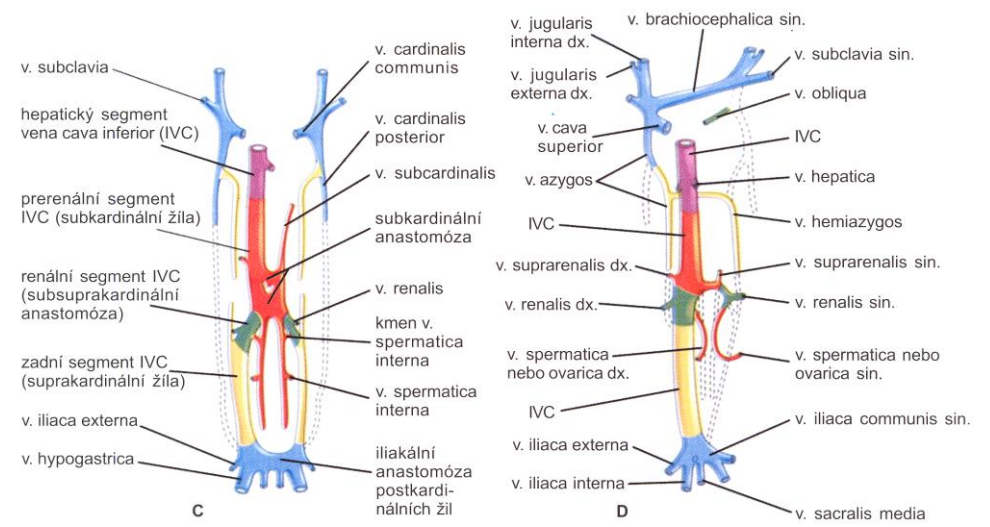
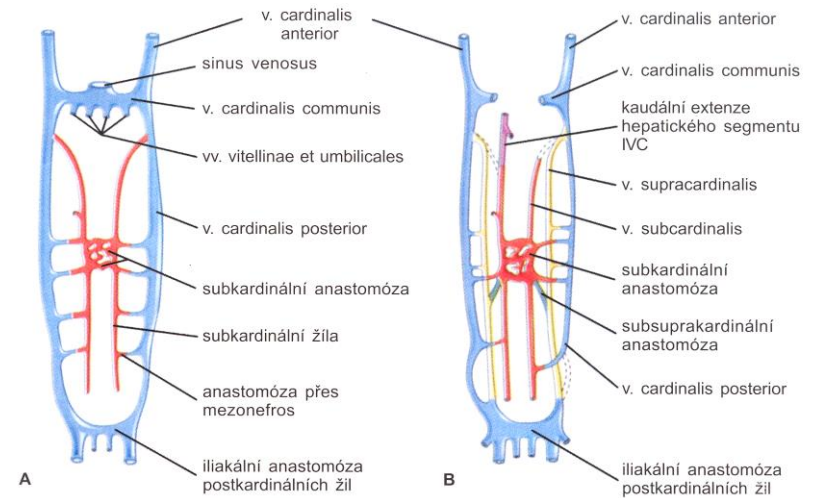
# DEVELOPMENT OF VEINS

## Cardinal veins and development of vena cava inferior

- four principal segments
- 1 hepatic segment** (proximal part of v. omphalomesenterica = v. hepatica)
- 2 prerenal segment** (right v. subcardinalis)
- 3 renal segment** (anastomosis between v. subcardinalis and v. supracardinalis)
- 4 postrenal segment** (right v. supracardinalis)



**Vena cava superior:** right v. cardinalis communis and v. cardinalis anterior

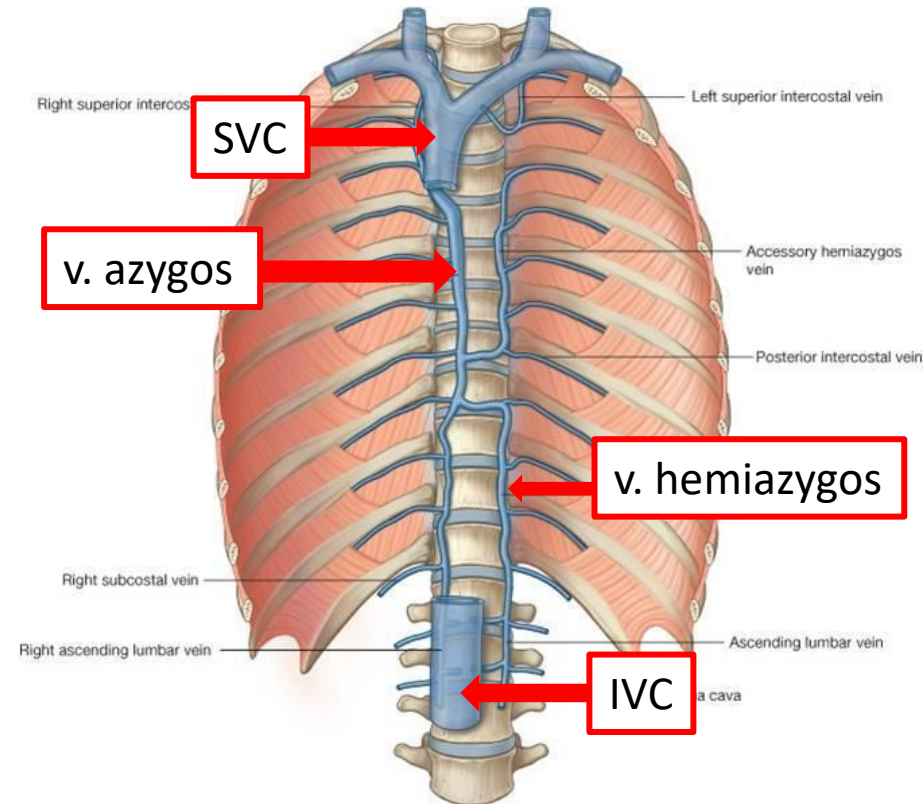
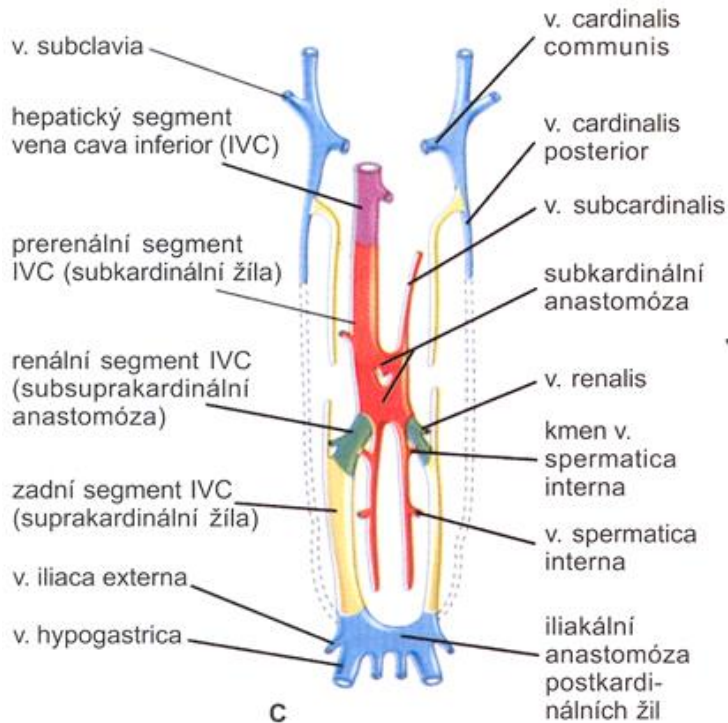


<span style="display: inline-block; width: 15px; height: 15px; background-color: #0070C0; border: 1px solid black;"></span> kardinální, umbilikální a vitelinní vény	<span style="display: inline-block; width: 15px; height: 15px; background-color: #C00000; border: 1px solid black;"></span> subkardinalní vény	<span style="display: inline-block; width: 15px; height: 15px; background-color: #FFD700; border: 1px solid black;"></span> suprakardinalní vény	<span style="display: inline-block; width: 15px; height: 15px; background-color: #800080; border: 1px solid black;"></span> hepatický segment	v. – vena w. – věny
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# DEVELOPMENT OF VEINS

## Anomalies of venae cavae

- **Double SVC:** persistence of left anterior cardinal vein; Abnormal CVC opens to right atrium through sinus coronarius
- **Left SVC:** right anterior cardinal vein and v. cardinalis communis degenerate
- **Absence of hepatic segment** of IVC: blood drained through v. azygos and hemiazygos into right atrium. Vv. hepaticae opens to right atrium individually.
- **Double IVC:** absence of anastomoses between primitive caudal veins.



# DEVELOPMENT OF VEINS

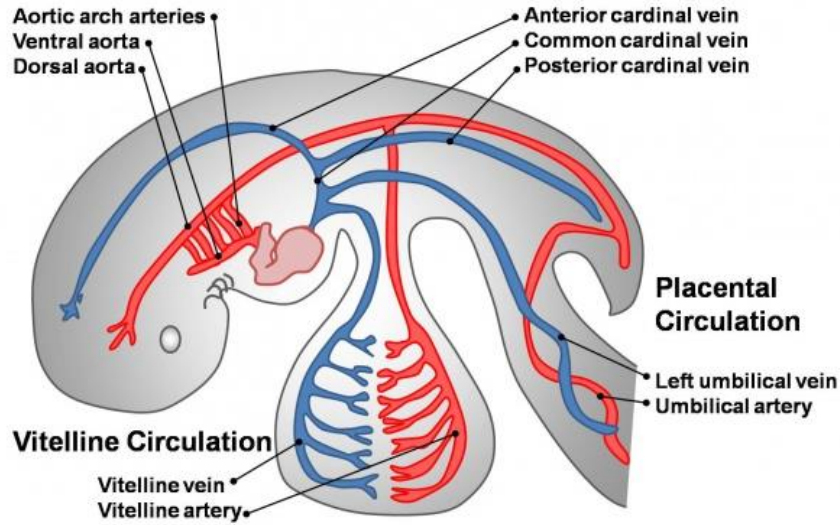
## Vv. omphalomesentericae

- bring blood from yolk sac
- septum transversum
- sinus venosus (together with umbilical veins as trunci vitelloumbilicales)
- growth of liver – separation of omphalomesenteric veins to proximal (yolk sac-liver) and distal parts (liver-heart)
- distal parts form anastomoses and develop into v. portae
- proximal parts form posthepatic part of IVC

## Vv. umbilicales

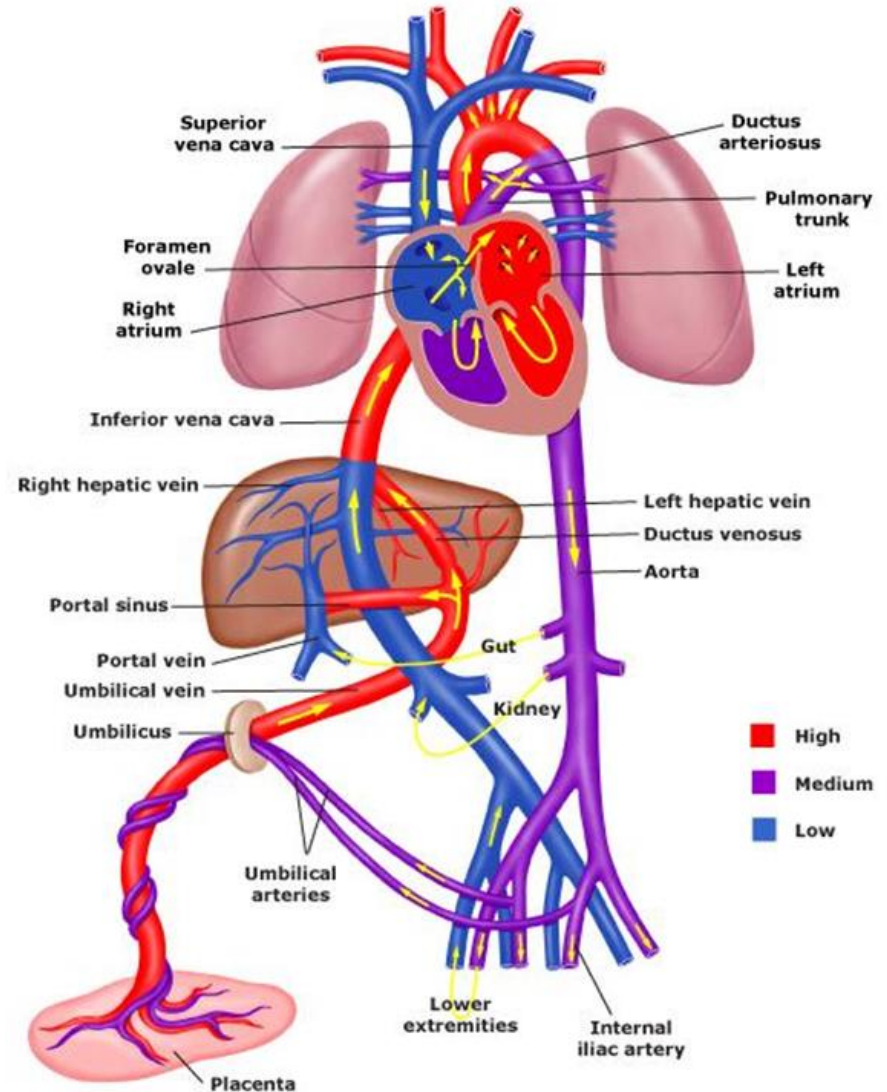
- begin in chorionic villi
- due to liver growth lose connection with sinus venosus
- right v. umbilicalis disappears
- distal part of left v. umbilicalis forms ductus venosus (ligamentum venosum post natally)

# DEVELOPMENT OF CARDIOVASCULAR SYSTEM

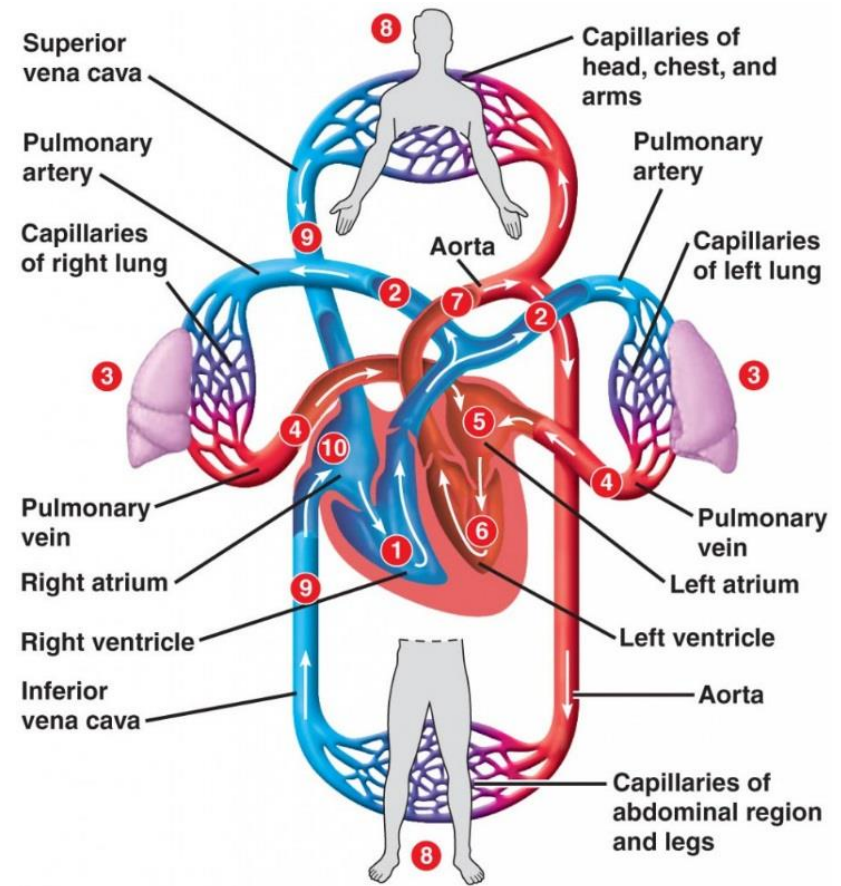
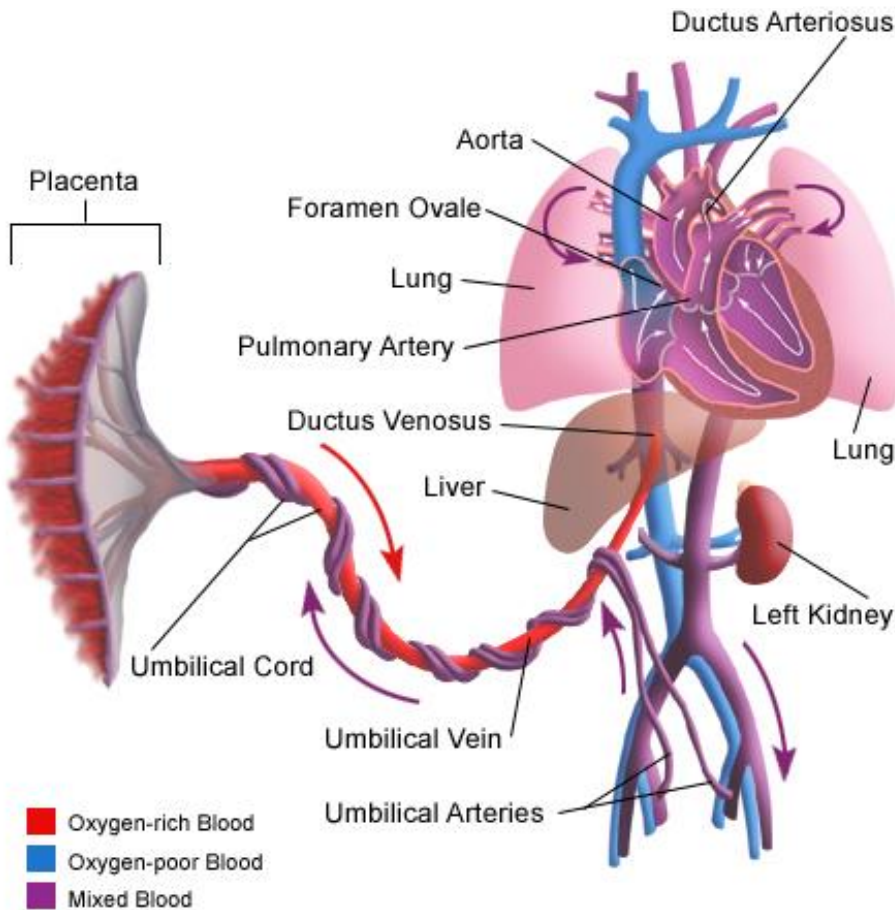


## Embryonic circulation

## Fetal circulation



## Fetal circulation



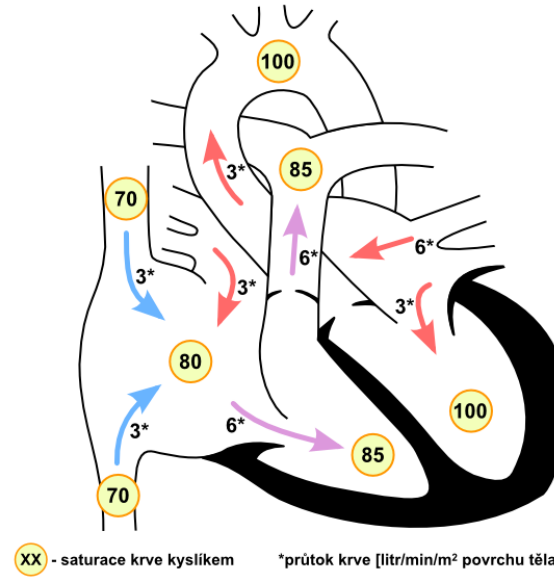
## Postnatal circulation

# DEVELOPMENT OF CARDIOVASCULAR SYSTEM

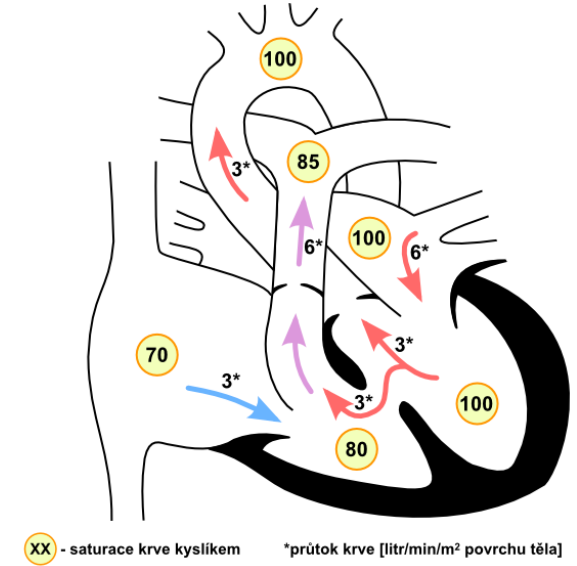
## Teratology

- Acardia
- Ectopia cordis
- Dextrocardia
- Atrial septal defects
- Ventricular septal defects
- Stenosis of truncus pulmonalis
- Atresia pulmonaris
- Tetra (penta)logy of Fallot
- Coartaction of aorta
- Ductus arteriosus apertus

Defekt síňového septa



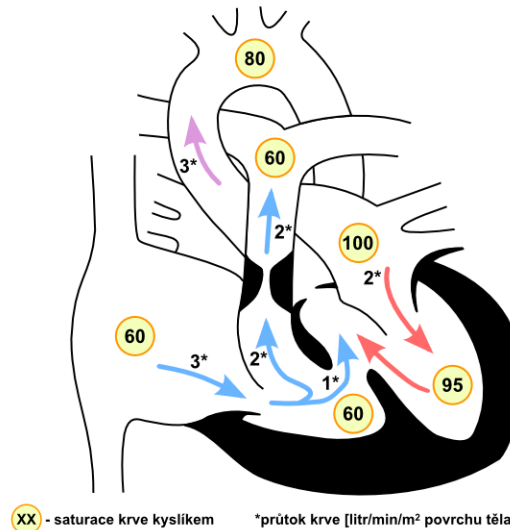
Defekt komorového septa



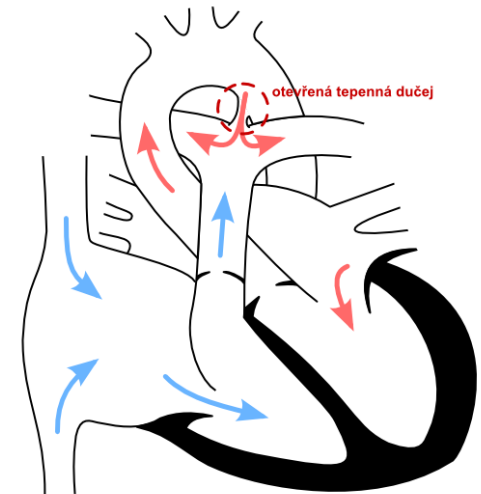
Koarktace aorty



Fallotova tetralogie



Otevřená tepenná dučej (PDA)



Thank you for attention