
Blood vessels
- vasculogenesis = vessels arise from mesenchymal blood islands
  - in week 3, cells named angioblasts condense and form blood islands within extraembryonic mesenchyme in the wall of yolk sac, connecting stalk, and chorion
  - in the embryo, cells migrate mainly from the intraembryonic mesoderm to form undifferentiated embryonic mesenchyme; in this mesenchyme, angioblasts condense into blood islands as well
  - the blood islands luminize, thus becoming primitive vascular canals lined with endothelial cells and containing primitive blood cells named erythroblasts
- angiogenesis = vessels sprout from existing vessels

Early bilateral circulation
- umbilical veins: these carry oxygenated blood from the chorionic villi → via the connecting stalk to the embryo → into the heart tube
- umbilical arteries: these carry blood from the dorsal aorta towards the chorionic villi
- vitelline artery: from the dorsal aorta → towards the extraembryonic vitelline circulation within the wall of yolk sac
- vitelline vein: from the vitelline circulation of the yolk sac → towards the heart
- segmental arteries arise from the dorsal aorta and pass between the body somites
- the venous drainage from the somites is collected via segmental veins which fuse into the anterior and posterior cardinal veins → these merge into the common cardinal vein
- the common cardinal vein finally collects the blood from the intersegmental veins and therefore from the body somites; the vein carries the blood to the heart

Unified circulation
- some parts of the early embryonic circulation, which consisted of paired blood vessels with bilateral symmetry, are reduced: either one of the paired vessels disappear, or the paired vessels merge to form a single vessel
- unified blood vessels:
  - single heart tube
  - single dorsal aorta
  - single vitelline artery and single vitelline vein (the left vitelline vein disappears)
  - single umbilical vein (the right umbilical vein disappears)

Embryonic and fetal circulation
- the umbilical vein carries blood saturated with oxygen and nutrients to the embryo
  - part of the blood mixes with the portal circulation, thus entering the liver sinusoids
  - part of the blood bypasses the liver via ductus venosus and enters the inferior vena cava
- the inferior vena cava enters the right atrium and the blood is mostly guided through the foramen ovale → from the right atrium to the left atrium
- the superior vena cava enters also the right atrium, but most of the blood goes to the right ventricle and then into the pulmonary trunk
but the pulmonary arteries are collapsed, they have a great vascular resistance, as the lungs are collapsed
  - most of the blood goes from the pulmonary trunk via ductus arteriosus into the aortic arch

**Aortic arches**
- series of paired (left+right) arteries, each of these supplying their pharyngeal arches in the 4th and 5th week
- they connect the ventral aorta with the dorsal aorta
- they originate in cranio-caudal sequence (as do the pharyngeal arches)
- during week 6, the arches undergo significant remodelling, thus establishing final anatomy and architectonics of the vascular supply of head, neck and upper thoracic region
- some of the arches develop symmetrically, some of them are modified on the left side in a different way than on the right side
- derivatives of the aortic arches
  - **1st aortic arch** → most of it disappears, a small portion persists as the maxillary artery
  - **2nd aortic arch** → most of it disappears, a small portion persists as the hyoid artery and the stapedial artery
  - **3rd aortic arch** → forms the common carotid artery and the first part of the internal carotid artery
  - **4th aortic arch**
    - right side: proximal portion of the right subclavian artery
    - left side: aortic arch from the left common carotid to the left subclavian arteries
  - **5th aortic arch**: forms incompletely and regressed
  - **6th aortic arch**
    - right side: right pulmonary artery
    - left side: left pulmonary artery and ductus arteriosus

**Derivatives of other embryonic arteries**
- dorsal intersegmental arteries branching from the aorta →
  - intercostal arteries
  - lumbar arteries
  - common iliac arteries
  - part of vertebral, subclavian, sacral lateral arteries
- lateral segmental arteries branching from the aorta →
  - renal arteries
  - suprarenal arteries
  - testicular and ovarian arteries
- umbilical arteries → proximal part = superior vesical arteries; distal part obliterates into medial umbilical ligaments
- vitelline arteries →
  - coeliac trunk
  - superior mesenteric artery
  - inferior mesenteric artery
Veins
- vitelline veins = omphalomesenteric veins
- umbilical vein
- cardinal veins and their branches
  o subcardinal veins drain blood from kidneys
  o sacrocardinal veins drain blood from the lower extremities
  o supracardinal veins drain blood from the intercostal veins (from the thoracic wall)

Derivatives of embryonic/fetal veins
- left umbilical vein → round ligament of liver (lig. teres hepatitis)
- ductus venosus obliterates into the ligamentum venosum
- vitelline veins →
  o hepatic portal system, liver sinusoids, portal vein
  o hepatic vein
  o intrahepatic part of the inferior vena cava
  o superior mesenteric vein
- anterior cardinal vein →
  o superior vena cava (on the right side)
  o left brachiocephalic vein (on the left side)
  o internal jugular vein
- posterior cardinal vein obliterates
- subcardinal veins (kidney region) →
  o inferior part of the inferior vena cava (on the right side)
  o renal veins, suprarenal vein
  o testicular veins/ovarian veins
- supracardinal veins
  o azygos vein (right side)
  o hemiazygos vein (left side)
  o part of the inferior vena cava between kidney and liver

Circulatory changes at birth
- respiration starts → expansion of lungs → the vascular resistance of pulmonary arteries drops → blood enters the pulmonary circulation instead of the ductus arteriosus → increased venous return into the left atrium → septum primum is compressed against the septum secundum → foramen ovale closes (it fuses during the 1st year in 80% individuals; it persists in 20% of individuals as a potential communication between the left and the right atrium (probe patent foramen ovale)
- smooth muscle in the ductus arteriosus contracts (due to an increase in PO$_2$, due to a drop in vasoactive prostaglandins and due to bradykinin released from lungs during the inflation); the ductus closes, its tunica intima proliferates and the ductus obliterates within 1-3 months
- arterial spasm (vasoconstriction) of umbilical arteries (due to a greater PO$_2$) → functional closure a few minutes after birth; anatomical obliteration within 2-3 months
- uterine contractions in the 3rd stage of the birth → most of the blood flows from the placenta into the fetal circulation → umbilical veins collapse
Arterial defects

- persisting ductus arteriosus
- coarctation (=narrowed lumen) of aorta
  - preductal type = proximal to the ductus arteriosus; d. arteriosus persists
  - postductal type = distal to the ductus arteriosus; d. arteriosus obliterates and collateral circulation between the proximal and distal aorta develops to bridge the narrowed aorta; this collateral circulation is established by way of increased intercostal arteries and internal thoracic arteries
- abnormal origin of the right subclavian artery distally to the origin of the left subclavian artery
- double aortic arch: the right dorsal aorta persists and the double arch forms a vascular ring surrounding the trach and the oesophagus
- right aortic arch: left 4th aortic arch obliterates and the right 4th arch persists instead

Venous defects

- double inferior vena cava: the left sacrocardinal vein fails to lose its connection with the left subcardinal vein
- missing inferior vena cava: the right subcardinal vein does join hepatic circulation, but carries blood into the right supracardinal vein
- left superior vena cava: persisting left anterior cardinal vein