DEVELOPMENT OF THE CIRCULATORY SYSTEM

LECTURE 5
REVIEW OF CARDIAC ANATOMY

- Heart
  - 4 chambers
  - Base and apex
  - Valves
  - Pericardial sac
  - 3 layers: epi, myo, endo cardium

- Major blood vessels
  - Aorta and its branches
  - Formation of the vena cava
  - Coronary arteries
FORMATION OF BLOOD VESSELS

• Derived from mesoderm
• Precursor cells called angioblasts develop into blood vessels
• 3 primary mechanisms
  • 1. Vasculogenesis = generally produce veins (and dorsal aorta)
  • 2. Angiogenesis = produce arteries
  • 3. combination of both = produce capillaries and small arterioles and venules
FORMATION OF BLOOD VESSELS

• Vasculogenesis
  • Occurs by coalescence of angioblasts to form primitive vascular channels

• Angiogenesis
  • Forms vascular channels by budding or branching from existing blood vessels
  • Similar mechanism in cancer. Tumor cells produce angiogenesis growth factor to increase blood flow into a tumor

• Combination
  • Invasion of existing vascular buds by migrating angioblasts
FORMATION OF THE HEART

• Arise from splanchnic mesoderm at the level of the pharynx
• Mesoderm from both sides fuse together as the foregut is produced, creating a single tube of splanchnic mesoderm = future heart
• Cardiac primordia are composed initially of 2 layers
  • Endocardium: inner layer ➔ endothelial layer
  • Myocardium: outer layer (eventually becomes the middle layer) ➔ muscular layer
• As the cardiac mesoderm fuse, a third layer is formed from the cardiac primordia = the epicardium ➔ becomes the pericardium or cardiac sac
FORMATION OF THE HEART

- From a straight tubular form, the heart changes in shape into an S-shaped configuration
  - The bottom (caudal) part will form the atrium
  - The top (cephalic) part will form the ventricles
- The veins converging to enter the heart become confluent into a chamber called the sinus venosus, which opens into the atrium
- From the ventricle, blood will flow out of the heart into the bulbus cordis and truncus arteriosus.
  - The bulbus cordis will merge with the ventricle to form part of the right ventricle.
FORMATION OF THE HEART

- The S-shaped single tube heart further bends upon itself, producing the normal configuration of the atrium and ventricles (atrium is cephalic, and ventricles are caudal)
  - The ventricle will move forward and the atrium will move to the back of the ventricle.
- Separating the atrium and ventricle is a narrowed portion called the atrioventricular junction, containing endocardial cushions, which eventually form the atrio-ventricular valves
Aortic roots
Pericardial cavity
Bulbus cordis
Pericardium

A

Primitive left atrium

Left ventricle

B

Truncus arteriosus
Primitive right atrium
Conus cordia
Trabeculated part of right ventricle
Interventricular sulcus

Primitive left atrium
PARTITIONING OF THE HEART

• Eventually, the atrium and ventricle further dilate allowing a septum to divide each chamber into right and left halves
  • Within these chambers are constricted areas due to thickenings in the endocardium, called endocardial cushion tissue
  • Within the endocardial cushion tissue are masses of connective tissue matrix called cardiac jelly
PARTITIONING OF THE HEART

• These endocardial cushions grow from from 3 areas, one from each side of the heart tube, and finally at the atrioventricular junction, to form the heart septa, dividing the heart into right and left halves.
Formation of septum by growth of opposite ridges
PARTITIONING OF THE HEART

- Interatrial septum
  - One partition grows from the middle endocardial cushion, called the septum primum, which has an opening in its middle or the ostium primum (interatrial foramen primum), allowing blood flow from the right side to the left side of the heart.

- Interventricular septum
  - A septum grows from the endocardial cushion at the apex and from the endocardial cushion at the AV junction.
PARTITIONING OF THE HEART

- As the ostium primum closes, another hole opens above the septum primum called the ostium secundum
  - Starts as small perforations, due to apoptosis of some cells in the area
  - These rapidly expand and unite to form a single opening called the ostium secundum (interatrial foramen secundum)
  - This allows blood flow from the RA into the LA of the heart, to prevent the left heart from collapsing on itself
  - Remember: there is as yet no pulmonary circulation to bring blood into the left side of the heart
PARTITIONING OF THE HEART

• A second interatrial septum is formed from the top margin of the atrium, just to the right of the first septum, called septum secundum
  • This forms a partial blockage of the foramen secundum, producing a valve
  • The septum secundum will have a small opening into the ostium secundum called the foramen ovale
  • The foramen ovale and ostium secundum acts as a one way valve from the right atrium to the left atrium
  • This has important structural and physiological aspects in fetal circulation.
PARTITIONING OF THE HEART

- The sinus venosus shifts from the midline to the right, and opens exclusively into the right atrium
  - This eventually combines with the right atrium, receiving blood from two major vessels, the superior vena cava and inferior vena cava
- Formation of the interventricular septum
  - Similar with formation of the interatrial septum
  - Ridges grow from the apex and from the endocardial cushion at the AV junction and these meet at the middle.
PARTITIONING OF THE HEART

• There is complete division of the right and left sides of the heart, except at the foramen ovale and foramen secundum or ostium secundum, which is essential for development

• Formation of the AV valves
  • Endocardial cushion at the AV junction grow into valves and papillary muscles, forming the tricuspid and bicuspid (mitral) valves
A

Septum primum
Ostium primum
Left endocardial cushion
Right endocardial cushion
Atrioventricular canal

C

Septum secundum
Ostium secundum
Septum primum
Endocardial cushion
Interventricular foramen

LA
RA
LV
RV
Interventricular septum (muscular portion)

Septum primum

Septum secundum

Foramen ovale

Membranous portion of the interventricular septum

Valve of oval foramen

Muscular portion of the interventricular system
PARTITIONING OF THE HEART

• The truncus arteriosus also divides into the aorta and pulmonary arteries
  • Mechanism is similar to the endocardial cushions and heart partitioning, but called truncoconal ridges.
  • Initially the truncus arteriosus exits primarily from the right ventricle. The truncoconal ridges then divide it at the middle, which eventually joins the interventricular septum. This allows formation of the aorta and pulmonary arteries.
  • These ridges also form the semilunar valves of the PA and Ao
  • The truncus arteriosus twists or spirals, such that the PA is in the left side and the Ao is in the right side and behind the PA.
FORMATION OF THE AORTA

- The truncus arteriosus separates into the pulmonary artery and aorta
- The aorta will travel upward as the paired ventral aorta to the head and arch back down to supply the rest of the body as the paired dorsal aorta
  - Forms the aortic arches: connections between the dorsal and ventral aortas
  - 6 aortic arches
- The dorsal aorta then fuses into one main vessel, and becomes the descending aorta.
  - A portion of the right dorsal aorta degenerates, just below the heart, separating blood flow from the upper and lower parts of the body.
# Aortic Arches

<table>
<thead>
<tr>
<th>Aortic Arch</th>
<th>Develops into</th>
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<tbody>
<tr>
<td>I, II, III</td>
<td>Merge into the common carotid arteries and other head and neck arteries</td>
</tr>
<tr>
<td>IV</td>
<td>Right arch becomes the right subclavian artery</td>
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<tr>
<td></td>
<td>Left arch becomes the arch of the aorta</td>
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<tr>
<td>V</td>
<td>Remains vestigial and disappears</td>
</tr>
<tr>
<td>VI</td>
<td>Right arch becomes the right pulmonary artery</td>
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<tr>
<td></td>
<td>Left arch becomes the left pulmonary artery and ductus arteriosus</td>
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FORMATION OF THE MAJOR VEINS

• The systemic venous system consists of the anterior and posterior cardinal veins which empty into the right and left common cardinal veins, and ultimately into the sinus venosus.

• The right common cardinal vein
  • The right anterior cardinal vein becomes the superior vena cava
  • The right posterior cardinal vein becomes the inferior vena cava

• The left common cardinal vein
  • becomes the coronary sinus (draining blood from the coronary vessels which supply blood to the heart muscles)
FORMATION OF THE MAJOR VEINS

- The vitelline veins (omhalomesenteric veins) drains blood from the yolk sac
- The umbilical veins brings blood from the placenta to the embryo
- All these drain into the sinus venosus. The sinus venosus eventually merges with the right atrium.
- The pulmonary veins arise from the lung buds and drain directly into the left atrium (although a few short pulmonary veins grow from the left atrium to the lungs)
FORMATION OF THE MAJOR VEINS

• The inferior vena cava is formed as follows
  • The vitelline veins and umbilical veins join together to meet with the posterior cardinal vein to become the inferior vena cava
  • The vitelline veins develop into the hepatic portal system which drains blood from the developing intestines and liver. All blood from the intestines first drains into the liver for processing before going to the heart for circulation.
  • The umbilical vein, is initially paired. The right umbilical vein degenerates, leaving the left as the sole vessel from the placenta to the embryo. As it enters the fetus and is at the level of the liver, this becomes the ductus venosus
CHANGES IN CIRCULATION FROM FETUS TO BIRTH

• 2 major changes
  • Abrupt cutting off of the placental blood flow
  • Immediate assumption by the lungs for respiration

• Fetal blood flow
  • Placenta → umbilical veins → ductus venosus → inferior vena cava (joined by the hepatic veins) → right atrium → foramen ovale → left atrium → left ventricle → aorta → head
  • Superior vena cava → right atrium → right ventricle → pulmonary artery → lungs → pulmonary veins → left atrium → left ventricle → aorta → dorsal aorta → body
  • Pulmonary artery → ductus arteriosus → aorta
  • Aorta → umbilical arteries → placenta
CHANGES IN CIRCULATION FROM FETUS TO BIRTH

• At birth
  • Cessation of placental flow shrinks the umbilical vessels.
  • Umbilical vein close and the ductus venosus becomes the round ligament of the liver (part of the falciform ligament)
  • Umbilical arteries close and becomes the medial umbilical ligaments
  • Ductus arteriosus closes by muscular contractions through the following mechanisms
    • As the lungs expand, it releases a substance called bradykinin which stimulates contraction of the muscles in the DA
    • Becomes the ligamentum arteriosum
  • Umbilical blood flow ceases decreasing pressure in the right atrium, while ductus arteriosus closes increasing blood flow to the lungs and to the left atrium. This increased pressure functionally closes the foramen ovale.
CONGENITAL HEART DEFECTS

- Atrial Septal Defect (ASD)
- Ventricular Septal Defect (VSD)
- Patent Ductus Arteriosus (PDA)
- Transposition of the Great Arteries (TGA)
- Persistent truncus arteriosus
- Double outlet right ventricle (DORV)
- Tetralogy of Fallot (TOF)