SEM-IV CC Study Materials

Comparative Vertebrate Anatomy- Circulatory System

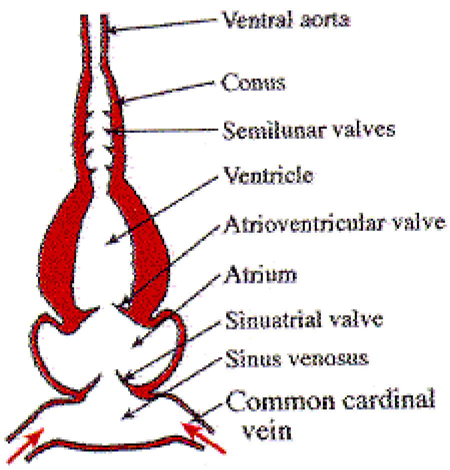
Vertebrate Circulatory Systems:

- transport gases, nutrients, waste products, hormones, heat, & various other materials
- consist of heart, arteries, capillaries, & veins:
    - Arteries
        - carry blood away from the heart
        - have muscular, elastic walls
        - terminate in capillary beds
    - Capillaries
        - have very thin walls (endothelium only)
        - are the site of exchange between the blood and body cells
    - Veins
        - carry blood back to the heart
        - have less muscle in their walls than arteries but the walls are very elastic
        - begin at the end of capillary beds
    - Heart
        - a muscular pump (cardiac muscle)
        - contains a pacemaker to regulate rate but rate can also be influenced by the Autonomic Nervous System

Vertebrate Hearts:

Cartilaginous fishes

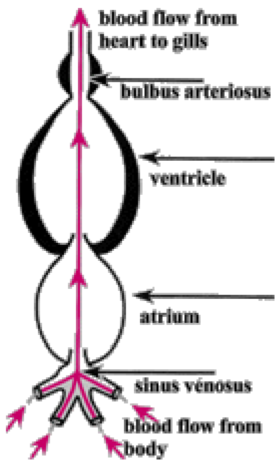
- single-circuit heart with 4 chambers: sinus venosus, atrium, ventricle, & conus arteriosus
    - the sinus venosus receives blood & is filled by suction when the ventricle contracts & enlarges the pericardial cavity
    - the atrium is a thin-walled muscular sac; an A-V valve regulates flow between atrium & ventricle

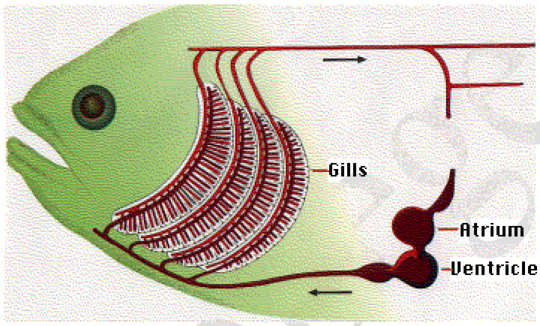


Hypothetical Ancestral Vertebrate Heart

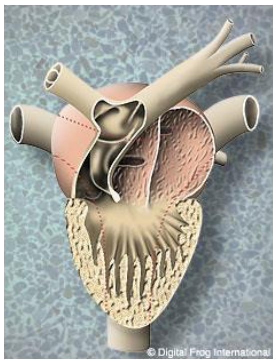
- the ventricle has thick, muscular walls
- the conus arteriosus leads into the ventral aorta (and a series of conal valves in the conus arteriosus prevent the backflow of blood)

Teleosts - heart is similar to that of cartilaginous fishes, except a bulbus arteriosus (a muscular extension of the ventral aorta) is present rather than a conus arteriosus (a muscular extension of the ventricle)

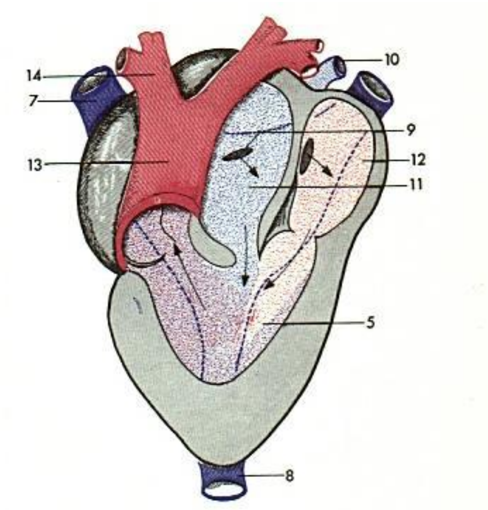




Lungfish & amphibians - modifications are correlated with the presence of lungs & enable oxygenated blood returning from the lungs to be separated from deoxygenated blood returning from elsewhere (see **HHMI Biointeractive**):



- Partial or complete partition within atrium (complete in anurans and some urodeles)
- Partial interventricular septum (lungfish) or ventricular trabeculae (amphibians) to maintain separation of oxygenated & unoxygenated blood
- Formation of a spiral valve in the conus arteriosus of many dipnoans and amphibians. The spiral valve alternately blocks & unblocks the entrances to the left and right pulmonary arches (sending unoxygenated blood to the skin & lungs).
- Shortening of ventral aorta, which helps ensure that the oxygenated & unoxygenated blook kept separate in the heart moves directly into the appropriate vessels



3 CHAMBERED FROG HEART

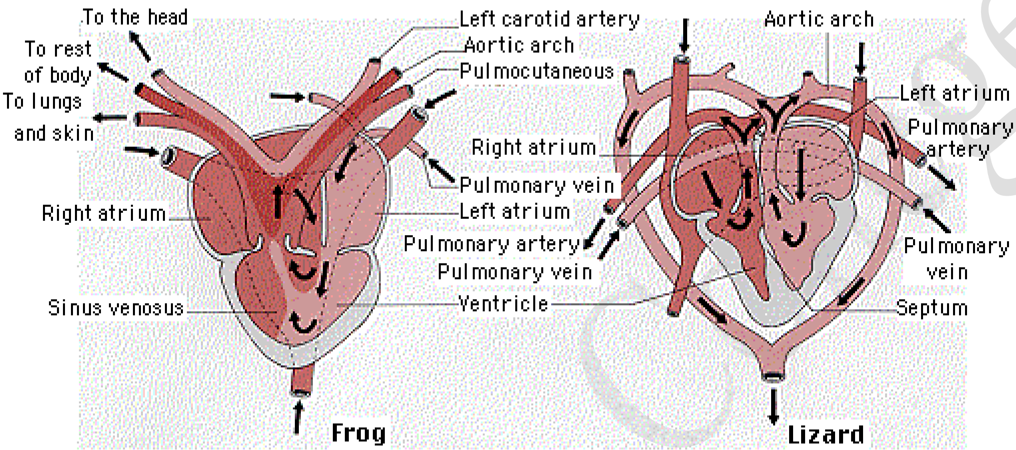
5 = ventricle, 11 = right atrium, 12 = left atrium, 13 = conus arteriosus

Amniotes:

1 - Heart consists of 2 atria & 2 ventricles &, except in adult birds & mammals, a sinus venosus

2 - Complete interatrial septum

3 - Complete interventricular septum only in crocodilians, birds, & mammals; partial septum in other amniotes



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Arterial channels - supply most tissues with oxygenated blood (but carry deoxygenated blood to respiratory organs). In the basic pattern:

1 - the ventral aorta emerges from heart & passes forward beneath the pharynx

2 - the dorsal aorta (paired above the pharynx) passes caudally above the digestive tract

3 - six pairs of aortic arches connect the ventral aorta with the dorsal aortas

Aortic arches of fishes - general pattern of development of arches in cartilaginous fishes:

1 - Ventral aorta extends forward below pharynx & connects developing aortic arches. The first pair of arches develop first.

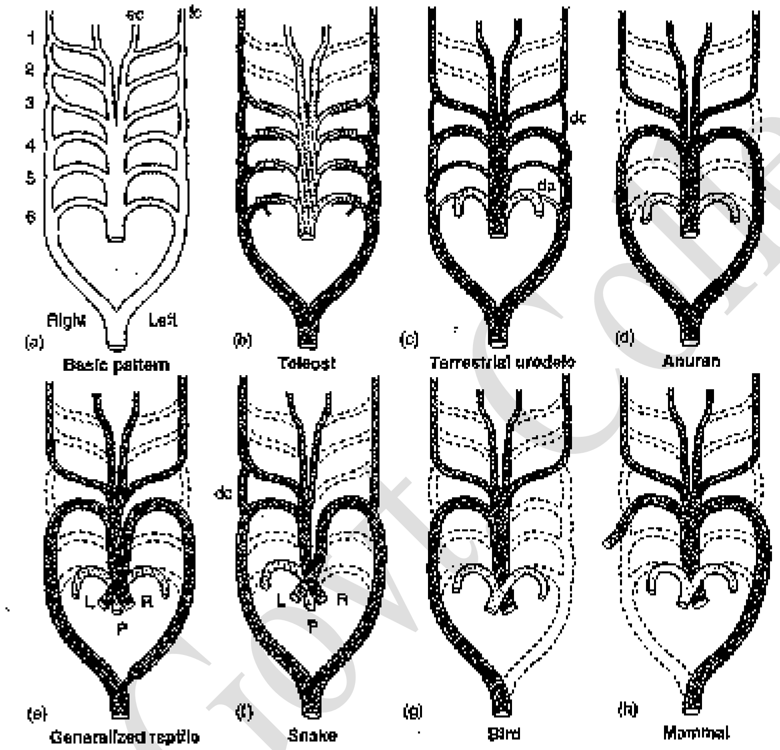
2 - Segments of first pair are lost & remaining sections become efferent pseudobranchial arteries

3 - Other pairs of arches (2 - 6) give rise to pre- & posttrematic arteries

4 - Arches 2 - 6 become occluded; dorsal segments = efferent branchial arteries & ventral segments = afferent branchial arteries

5 - Capillary beds develop within nine demibranchs

Result: Blood entering an aortic arch from ventral aorta must pass through gill capillaries before proceeding to dorsal aorta



Teleosts:

- the same changes convert 6 pairs of embryonic aortic arches into afferent & efferent branchial arteries
- arches 1 & 2 are usually lost

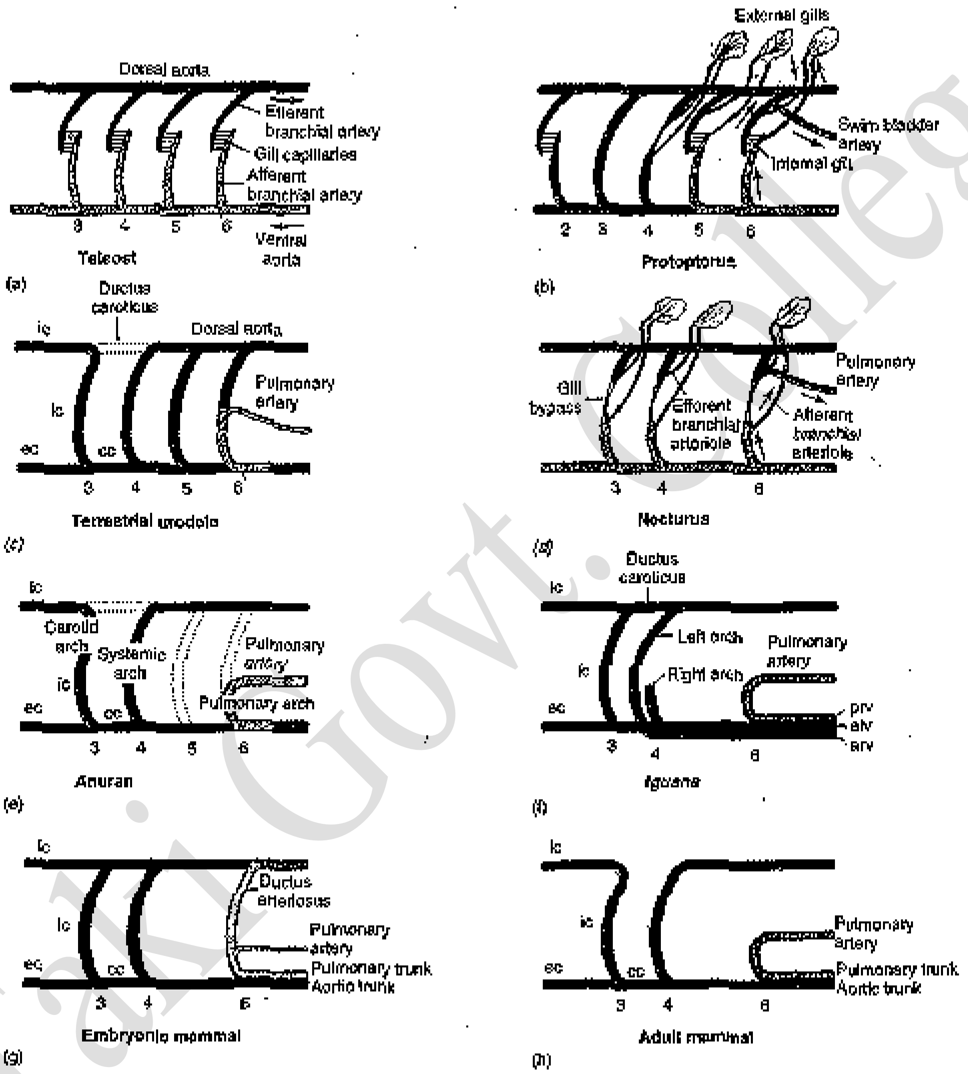
Lungfish:

- the pulmonary artery branches off the 6th aortic arch and supplies the swim bladder (& this is the same way that tetrapod lungs are supplied)

Aortic arches of tetrapods - embryos have 6 pairs of aortic arches:

- but the 1st & 2nd arches are temporary & not found in adults

- the 3rd aortic arches & the paired dorsal aortas anterior to arch 3 are called the internal carotid arteries
- the 4th aortic arches are called the systemic arches
- the 5th aortic arch is usually lost
- the pulmonary arteries branch off the 6th arches & supply blood to the lungs

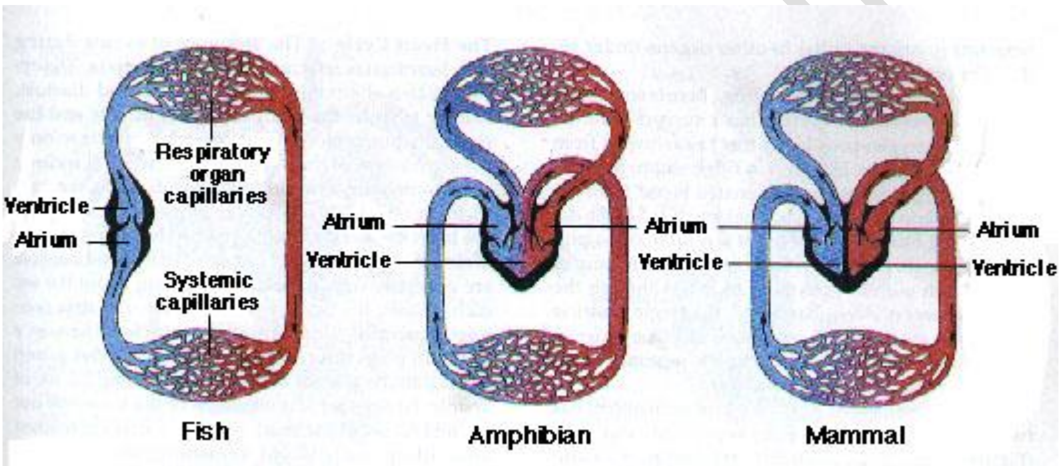


Further modifications of tetrapod arches:

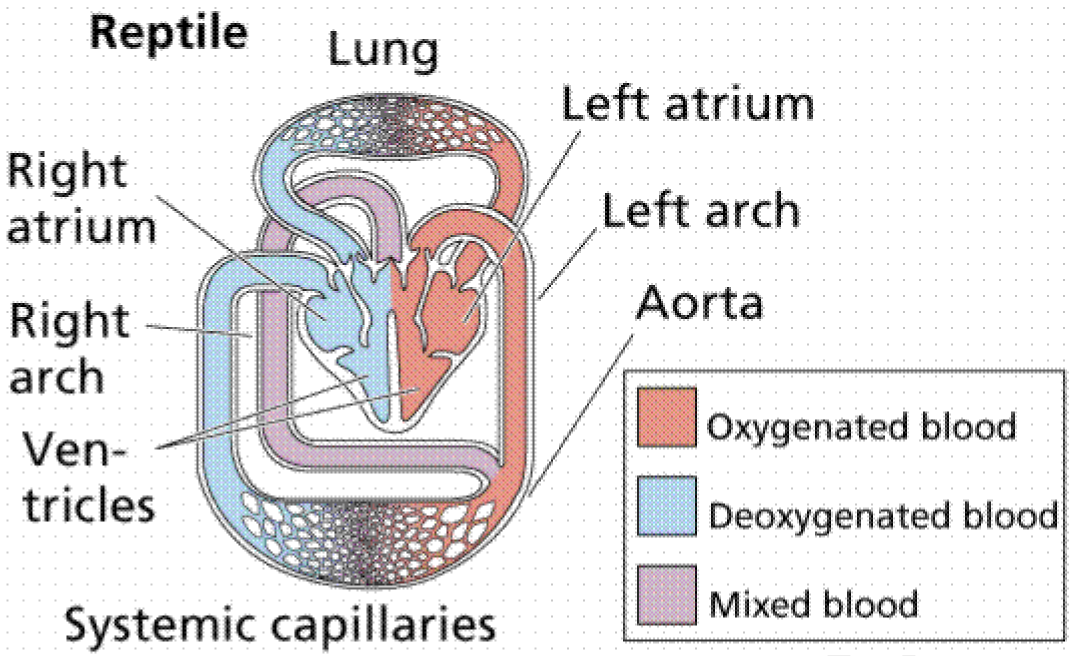
Amphibians:

- Urodeles - most terrestrial urodeles have 4 pairs of arches; aquatic urodeles typically have 3 pairs (III, IV, & VI)

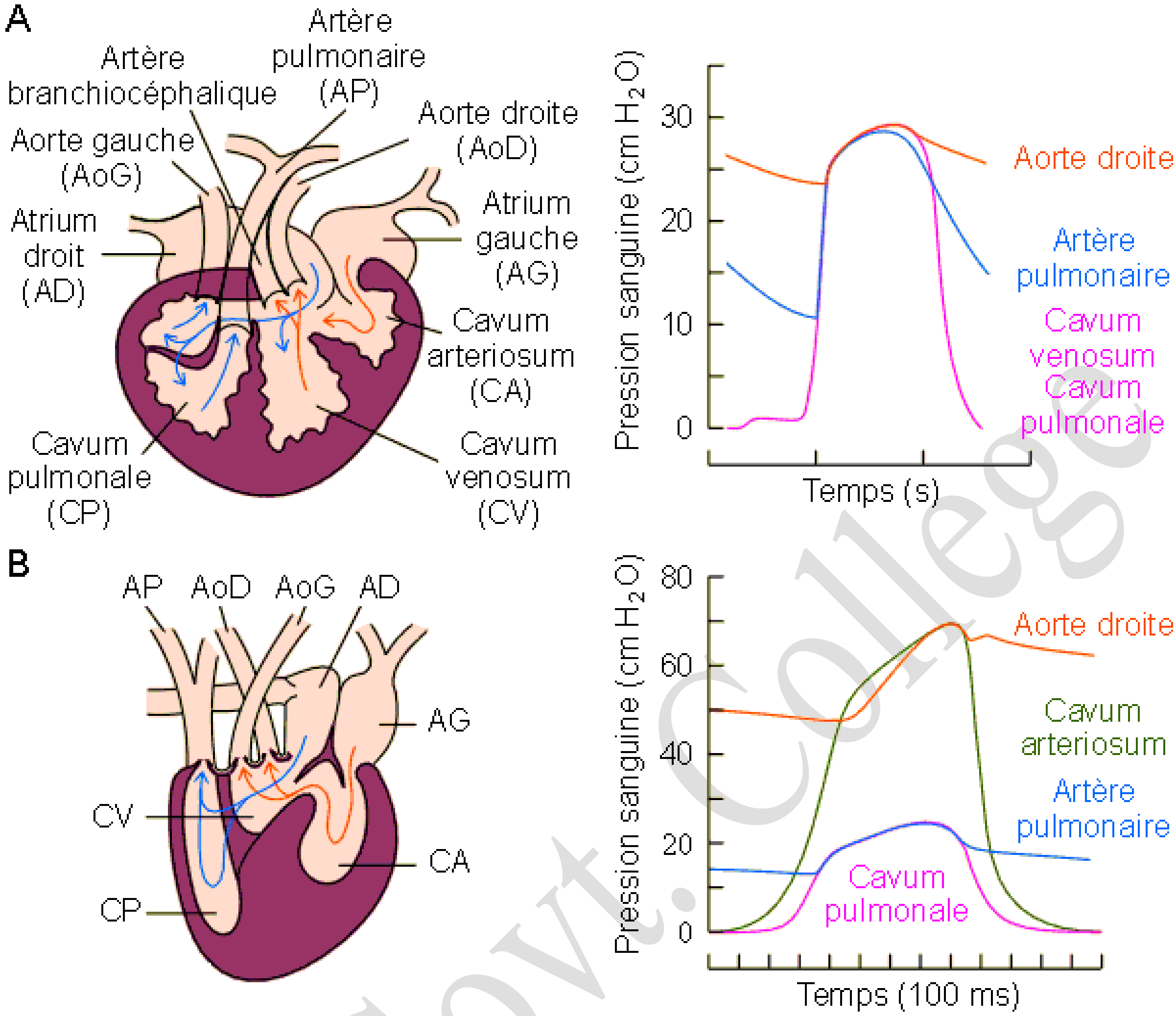
- Anurans - have 4 arches early in development (larval stage); arch VI develops a pulmonary artery (to lungs) while arches III, IV, & V supply larval gills. At metamorphosis:
    - aortic arch 5 is lost
    - the dorsal aorta between arches 3 & 4 is lost, so blood entering arch 3 (carotid arch) goes to the head
    - a segment (ductus arteriosus) of arch 6 is lost so blood entering this arch goes to the skin & lungs
    - aortic arch 4 (systemic arch) on each side continue to the dorsal aorta & distributes blood to the rest of the body
    - Oxygenated blood from the left atrium & deoxygenated blood from the right are largely kept separate in the ventricle by:
        - Ventricular trabeculae
        - Spiral valve in the conus arteriosus



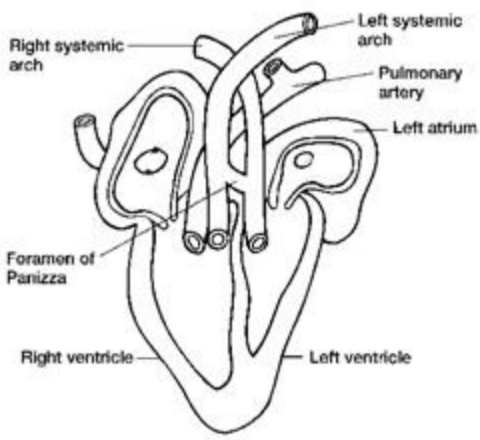
- Reptiles - 3 aortic arches in adults (III, IV, & VI)
    - Ventral aorta - no spiral valve but truncus arteriosus is split into 3 separate passages: 2 aortic trunks & a pulmonary trunk. As a result:
        - pulmonary trunk emerges from the right ventricle & connects with 6th aortic arches (deoxygenated blood from right atrium goes to lungs)
        - one aortic trunk comes out of left ventricle & carries oxygenated blood to the right 4th aortic arch & to carotid arches
        - the other aortic trunk appears to come out of right ventricle & leads to left 4th aortic arch. So, does the left 4th arch carry oxygenated blood?



Turtles, snakes, & lizards - the interventricular septum is incomplete where right & left systemic arches (4th) leave the ventricle & trabeculae in that region of the heart form a ‘pocket’ called the cavum venosum. Oxygenated blood from the left ventricle is directed into cavum venosum, which leads to the 2 systemic arches. As a result, both the left & right systemic arches receive oxygenated blood.

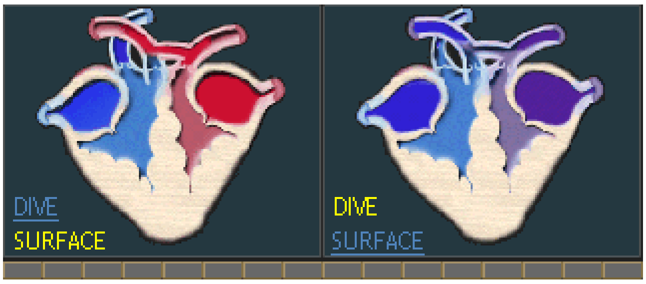


Crocodilians - ventricular septum is complete but a narrow channel called the Foramen of Panizza connects the base of the right & left systemic trunks

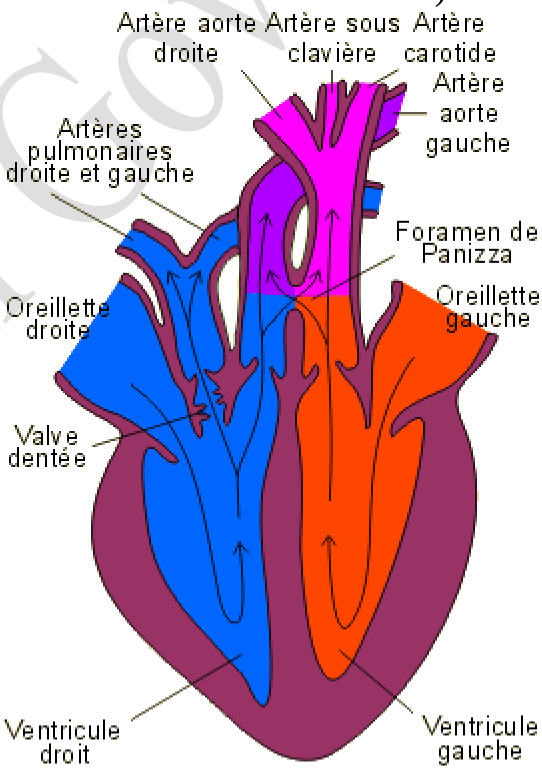


Role of the Foramen of Panizza in the crocodilian circulatory system:

- When a crocodilian is above water and breathing air, the semilunar valve in the right aorta remains closed because of higher pressure in the left & right aorta (higher than in the right ventricle). As a result, the right aorta receives blood from the left aorta (so both aortas carry oxygenated blood) and blood from the right ventricle (low in oxygen) passes only into the pulmonary artery (and goes to the lungs).

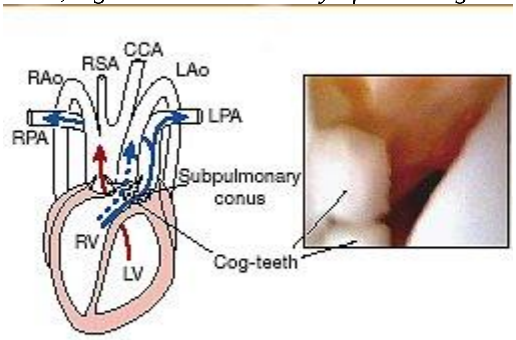


When a crocodilian is under water and not breathing, right ventricular pressure increases due to pulmonary resistance (vasoconstriction of blood vessels supplying the lungs). As a result, the semilunar valve in the right aorta is now forced open so some of the blood from the right ventricle now enters the right aorta rather than the pulmonary artery. This means that, rather than going to the lungs (where there is little or no oxygen anyway because the crocodilian is under water & not breathing), some of the blood enters the systemic (body) circulation. This means that vital organs & tissues (such as skeletal muscles and the central nervous system) will get an increased blood supply and additional oxygen. This, in turn, allows a crocodilian to stay underwater longer (which is most important because many crocodilians hunt by remaining underwater and 'ambushing' prey that come for a drink or to cool off).



Oreillette droite = right atrium, Oreillette gauche = left atrium, Ventricule droit = right ventricle, Ventricule gauche = left ventricle

***Secret of the crocodile heart*::** *By examining the heart of a crocodile, researchers have discovered how it is that an air-breathing creature can manage to cruise through the murk, for several hours without surfacing. The crocodile has a unique type of valve in its heart which actively controls blood flow between the lungs and the rest of the body. University of Queensland researcher, Craig Franklin, together with University of Goteborg colleague Michael Axelsson have been studying the heart of the estuarine crocodile, Crocodylus porosus. "These valves represent an absolute evolutionary novelty," said Dr Franklin. "They are further proof of the complexity and sophistication of the 'plumbing' and general anatomy of the crocodile family," Dr Franklin said.*



Unlike the passive flap-like valves of other vertebrates, the crocodile valve has cog teeth made up of nodules of connective tissue. The cog teeth mesh together, diverting blood away from lungs and into their bodies. The researchers have found that these "teeth" are controlled by the amount of adrenalin in the bloodstream."When the crocodile is relaxed, the absence of adrenalin acts to close the cog-teeth valves," Dr Franklin said. He said this mechanism may allow the crocodiles to dive for several hours without needing to resurface to breathe. The valves are situated in the crocodile's right ventricle, which pumps blood to the pulmonary artery feeding the lungs as well as to the left aorta which supplies the body. The cog-teeth valve can divert blood going to the lungs back into the body, a phenomenon known as a shunt. "In contrast, mammalian hearts are very inflexible with the blood supply to the lungs a separate activity to that feeding the body." - Abbie Thomas - ABC Science Online

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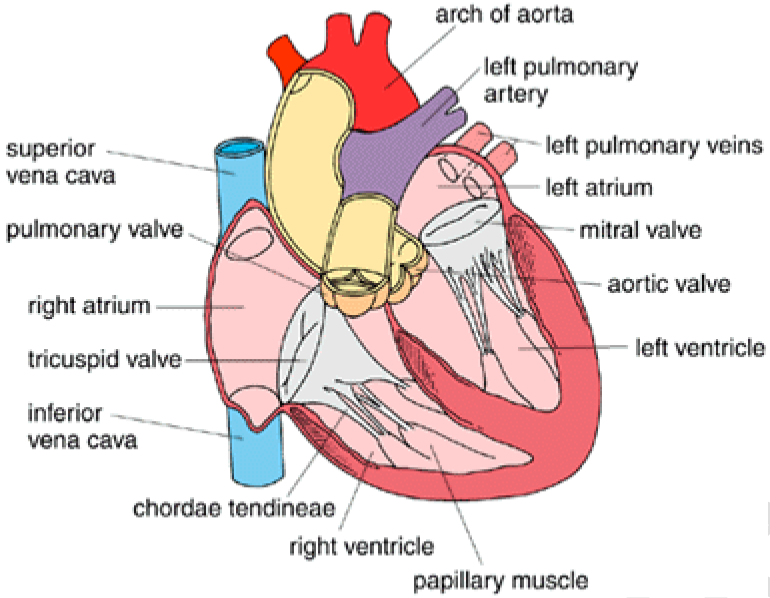
Birds & mammals - no mixing of oxygenated & unoxygenated blood; complete interventricular septum + division of ventral aorta into 2 trunks:

- Pulmonary trunk that takes blood to the lungs
- Aortic trunk that takes blood to the rest of the body

Result of modifications: All blood returning to right side of heart goes to the lungs; blood returning from lungs to the left side of heart goes to systemic circulation.



Venous channels - In early vertebrate embryos, venous channels conform to a single basic pattern. As development proceeds, these channels are modified by deletion of some vessels & addition of others. The primary venous pathways include:

- cardinals
- renal portal
- lateral abdominal
- hepatic portal
- coronary
- pulmonary

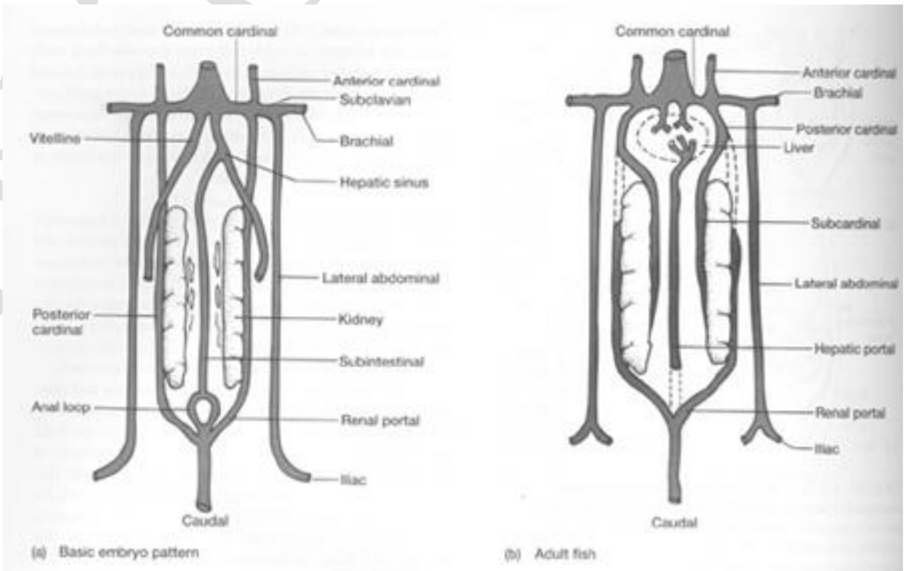
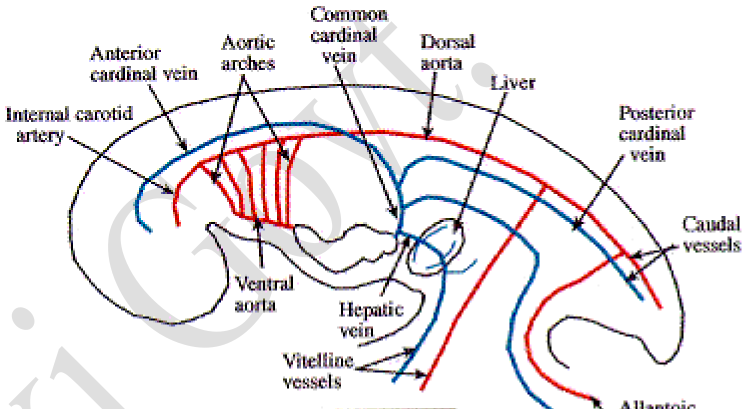


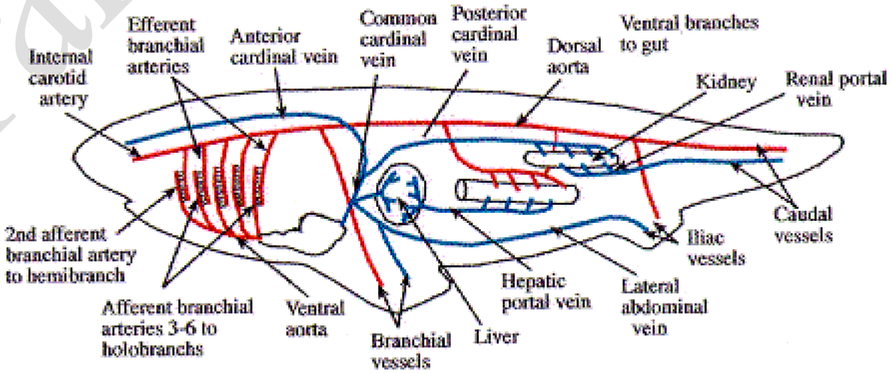
FIGURE 12.21 **Major veins.** The basic embryonic (a) and modified adult (b) pattern of major veins in the shark.

The venous channels in sharks:

- Cardinal streams - sinus venosus receives all blood returning to heart. Most blood enters sinus venosus via Common Cardinals. Blood from head is collected by Anterior Cardinals. Postcardinals receive renal veins & empty into Common Cardinals.
- Renal Portal stream - Early in development, some blood from caudal vein continues forward as Subintestinal (drains digestive system); this connection is then lost. During development, afferent renal veins (from old postcardinals) invade kidneys, & old postcardinals near top of kidneys are lost; all blood from tail must now enter kidney capillaries.
- Lateral Abdominal stream - LA vein starts at pelvic fin (where it receives iliac vein) & passes along lateral body wall; receives brachial vein, then turns, becomes Subclavian vein, & enters Common Cardinal vein.
- Hepatic Portal stream & Hepatic sinuses - Among 1st vessels to appear in vertebrate embryos are Vitelline veins (from yolk sac to heart). One Vitelline vein joins with embryonic Subintestinal vein (that drains digestive system) & becomes the Hepatic Portal System. Between liver & sinus venosus, 2 Vitelline veins are known as Hepatic sinuses.



Basic Pattern of Amniote Embryo



Basic Pattern of Adult Shark

Venous channels in other fishes are much like those of sharks except:

- Cyclostomes have no renal portals
- In most bony fishes the lateral abdominals are absent & the pelvic fins are drained by postcardinals

Venous channels of tetrapods - early embryonic venous channels are very similar to those of embryonic sharks. Changes during development include:

- **Cardinal veins & precavae** - embryonic tetrapods have posterior cardinals, anterior cardinals, & common cardinals
    - Urodeles - posterior cardinals persist between caudal vein & common cardinals in adults
    - Anurans, most reptiles, & birds - posterior cardinals are lost anterior to kidneys
    - Mammals - right posterior cardinal persists (azygos); part of left posterior cardinal persists (hemiazygos)

Terminology note: Common cardinals in tetrapods are called PRECAVAE; anterior cardinals are called INTERNAL JUGULAR VEINS.

    - Some mammals (e.g., cats & humans) lose the left precava; the left brachiocephalic carries blood from left side to right precava (sometimes called SUPERIOR VENA CAVA).

- **Postcava** - Both posterior cardinals begin to develop in embryos, but only one persists & becomes the POSTCAVA. The Postcava passes directly through the liver (sort of an 'expressway' for blood from kidneys & the posterior part of the body to the heart). The Postcava is sometimes called the INFERIOR VENA CAVA. In crocodilians, birds, & mammals, veins from hindlimbs connect directly to Postcava.

- **Abdominal stream**:
    - Early tetrapod embryos - paired lateral veins (like lateral abdominals of sharks) begin in caudal body wall near hind limbs, continue cranially, receive veins from forelimbs, & empty into cardinal veins or sinus venosus. As development continues:
        - Amphibians - 2 abdominal veins fuse at midventral line & form VENTRAL ABDOMINAL VEIN. Blood in this vessel goes into liver capillaries & abdominals anterior to liver are lost (so abdominal stream no longer drains anterior limbs).

- Reptiles - 2 lateral abdominals do not fuse but still terminate in liver capillaries (so do not drain anterior limbs; see diagram below).
- Birds - retain none of their embryonic abdominal stream as adults
- Mammals - no abdominal stream in adults

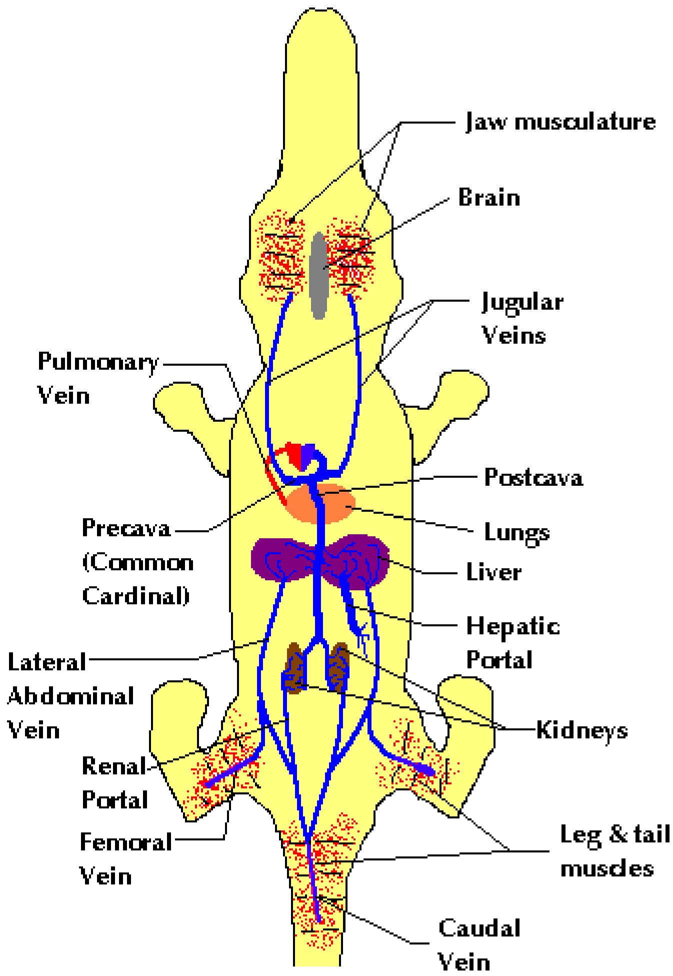


Fig. 2. Crocodylian venous circulation

- **Renal Portal system**:
  - Amphibians & some reptiles - acquires a tributary (external iliac vein; not homologous to mammalian external iliac) which carries some blood from the hind limbs to the renal portal vein. This channel provides an alternate route from the hind limbs to the heart.
  - Crocodilians & birds - some blood passing from hind limbs to the renal portal by-passes kidney capillaries, going straight through the kidneys to the postcava (see diagram above)
  - Mammals - renal portal system not present in adults

- **Hepatic Portal system** - similar in all vertebrates; drains stomach, pancreas, intestine, & spleen & terminates in capillaries of liver

- **Pulmonary veins** - carry blood from lungs to left atrium in lungfish & tetrapods

Circulation in a mammalian fetus & changes at birth:

In a developing fetus, blood obtains oxygen (& gives up carbon dioxide) via the placenta, not the lungs. As a result, blood flow must largely bypass the lungs so that oxygentated blood can get to other developing tissues. Getting oxygenated blood from the placenta back to the heart & out to the body as quickly and efficiently as possible involves a series of vessels & openings found only in a mammalian fetus:

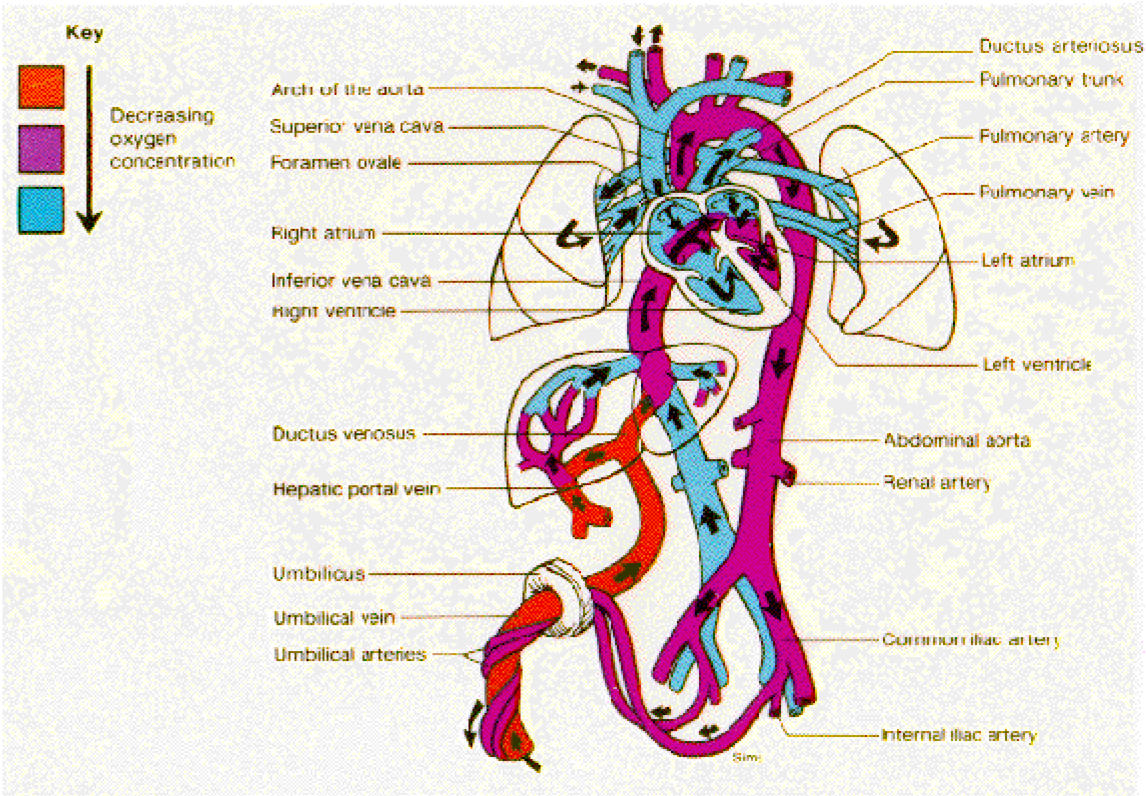
- blood (with oxygen & nutrients acquired in placenta) passes into umbilical vein
- blood largely bypasses the liver via the ductus venosus
- blood returns to the heart & enters right atrium, but much of the blood then bypasses the right ventricle & enters the left atrium via the foramen ovale
- blood that does enter the right ventricle largely bypasses the pulmonary circulation via the ductus arteriosus

Major changes at birth:

1 - Ductus arteriosus closes

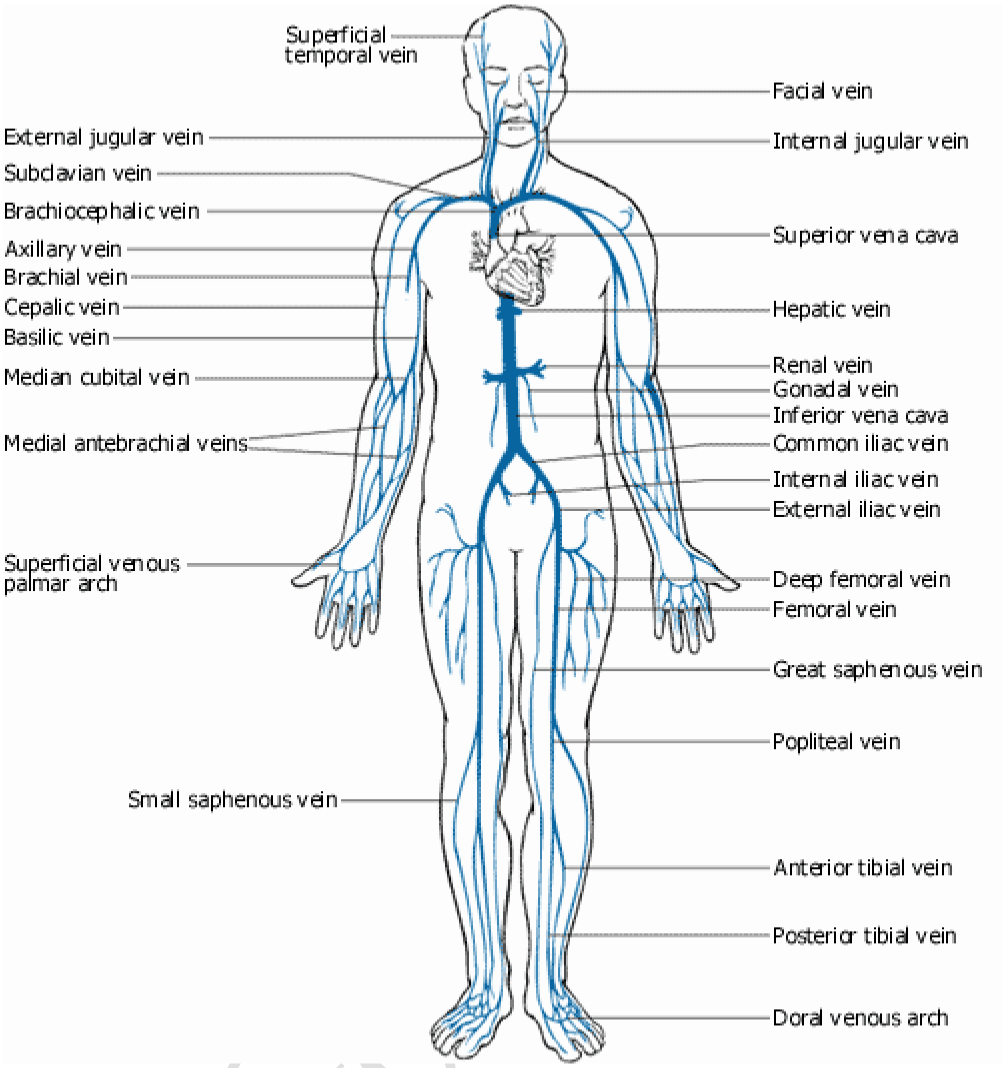
2 - Foramen ovale sealed off

3 - Blood no longer flows through umbilical vein



Lymphatic system - found in all vertebrates; consists of lymph vessels, lymph nodes, &, in some species, lymph hearts

- Lymph vessels
  - found in most soft tissues of the body & begin as blind-end lymph capillaries that collect interstitial fluid
  - valves present (in birds & mammals) that prevent backflow
  - empty into 1 or more veins (e.g., caudal, iliac, subclavian, & posterior cardinal)
- Lymph nodes - located along lymph vessels; contain lots of lymphocytes & macrophages (phagocytic cells)
- Lymph hearts - consist of pulsating smooth muscle that propels lymph fluid through lymph vessels; found in fish, amphibians, & reptiles


Superficial temporal vein
Facial vein
External jugular vein
Internal jugular vein
Subclavian vein
Brachiocephalic vein
Superior vena cava
Axillary vein
Brachial vein
Cepalic vein
Hepatic vein
Basilic vein
Renal vein
Gonadal vein
Median cubital vein
Inferior vena cava
Common iliac vein
Medial antebrachial veins
Internal iliac vein
External iliac vein
Superficial venous palmar arch
Deep femoral vein
Femoral vein
Great saphenous vein
Popliteal vein
Small saphenous vein
Anterior tibial vein
Posterior tibial vein
Doral venous arch