FUNCTION OF CARDIOVASCULAR SYSTEM

a transport system

- O2 and CO2 between lungs and tissues
- metabolites from Gastrointestinal tract (GIT) → store in tissues
- hormones and intracellular messengers between organs and between cells in a tissue
- waste products from tissue to sites of metabolism and excretion
- components of immune system → protect from disease

Components of cardiovascular system

heart

arteries

capillaries

venules and veins

Heart

a **muscular pump** forcing blood through blood vessels by its rhythmic contractions

4 chambers: right atrium, left atrium, right ventricle, left ventricle

atrium and ventricle on the **same side communicate**

right and left sides are completely separated by the **atrial and ventricular septae**

Arteries

convey blood to tissues, classified as:

- conducting arteries
- distributing arteries
- arterioles

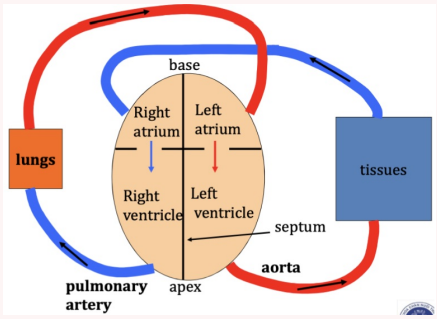
Capillaries

exchange between artery and vein	place for exchanging O2 and CO2

Venules and veins

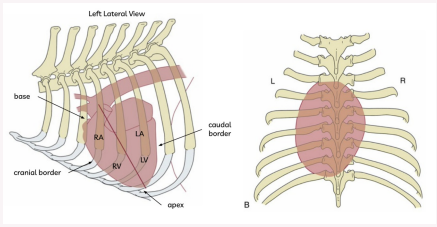
convey blood from tissues back to heart

Surface anatomy of the heart



lungs → **left atrium** (oxygenated blood) → **left ventricle** → **tissues** (via the systemic arterial system) → **right atrium** (deoxygenated venous blood) → **right ventricle** → **lungs** (via the pulmonary trunk)

Surface anatomy of the heart

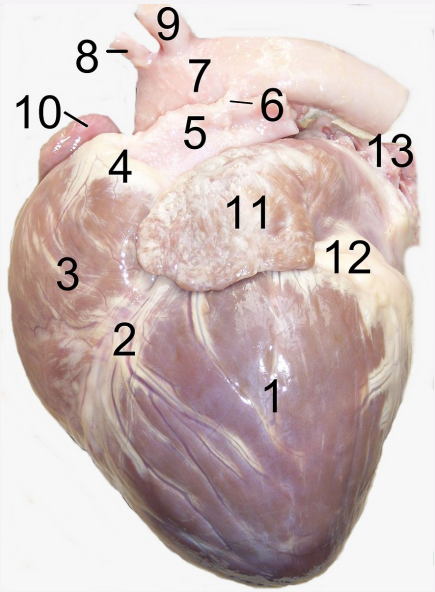


pulmonary: 3-4
aortic: 4-5
left AV valve: 5-6

base
- formed by atria
- lies at the junction of dorsal and middle third of the thorax
- cranial and caudal vena cava and pulmonary veins enter the atria at the base

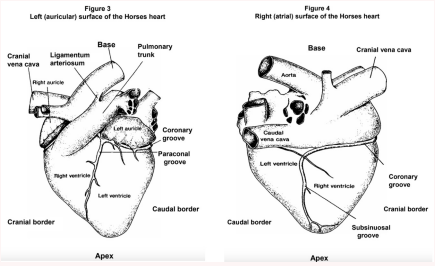
apex
- lies close to the sternum at about the level of the 6th costal cartilage

Left side of the heart

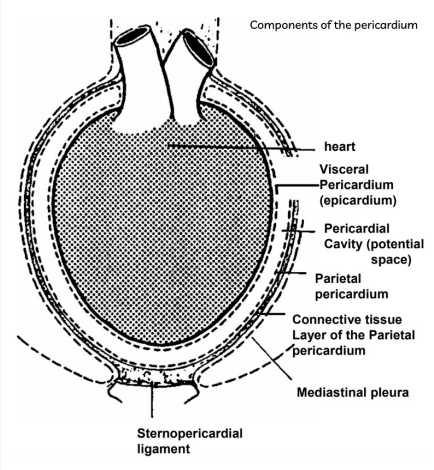


1. left ventricle
2. paraconal interventricular groove
3. right ventricle
4. coronary groove (fat fill)
5. pulmonary trunk
6. ligamentum arteriosum
7. aorta
8. brachiocephalic trunk
9. subclavian artery
10. right auricle
11. left auricle
12. coronary groove (contains fat and circumflex coronary vessels)
13. caudal vena cava

Surface of the Horses heart



PERICARDIUM



a close-fitting serous membrane covered the heart and origins of the major blood vessels

2 layers
- inner **visceral pericardium**
- outer **parietal (fibrous) pericardium**

Visceral pericardium (epicardium)

attached closely to heart wall

have a layer of mesothelial cells - secrete **pericardial fluid**; overlying connective tissue rich in elastic fibers - merges with myocardium

Parietal (fibrous) pericardium

3 layers

- inner squamous mesothelium
- collagen and elastic fibrous layer
- outer mediastinal pleura

→ give rise to a **ligamentous fold** which anchors the **apex** of the heart in its **position in the thorax**

- In horses, cattle and pigs this attaches to the **sternum** (sternopericardial ligament)

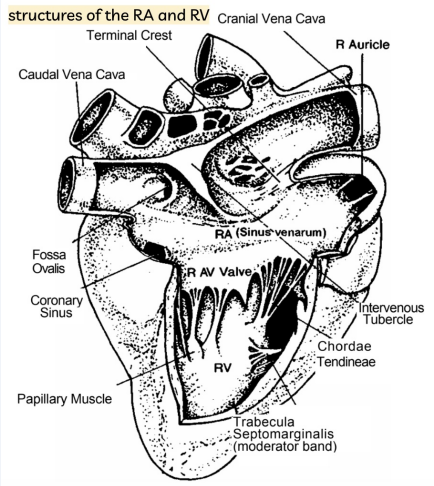
Parietal (fibrous) pericardium (cont)

- In carnivores it attaches to the **sternum by 2 ligaments** (by phrenicopericardial and sternopericardial ligaments)

pericardial cavity

- separated visceral and parietal pericardium
- contain a small volume of **lubricant pericardial fluid**

GENERAL ANATOMY OF THE HEART



right (atrial) surface

RIGHT ATRIUM

forms the **craniodorsal aspect** of the base

consists of main chamber (**sinus venarum**), and an **auricle** (blind ended sac) surrounds craniodorsal aspect of heart

receives blood from body via **venae canae**

⚲ **CAUDAL VENA CAVA** enters RA *caudodorsally*

▶ **coronary sinus**

- ventral to the entrance of caudal vena cava
- carries most of venous blood from heart muscle
- has a small **semilunar valve**

⚲ **CRANIAL VENA CAVA** enters RA *craniodorsally*

▶ **terminal crest** (an embryonic remnant of tissue)

- ventral to the entrance of cranial vena cava

RIGHT ATRIUM (cont)

- *no functional significance*

⚲ both conduct blood into RA from opposing directions → potentially causing considerable turbulence

⇒ **intervenous tubercle** projects ventrally from dorsal wall of RA - direct blood from both venae cavae towards right AV opening

RIGHT AZYGOUS VEIN

- drains blood from thoracic wall
- joins cranial vena cava (in horse, dog and some ruminants)
- enters heart directly between the vena cavae (in others)

LEFT AZYGOUS VEIN

- may present in ruminant and pig
- enters RA via coronary sinus

▶ inner surface of **sinus venarum** is mainly smooth

▶ **auricle** has **pectinate muscle**

a series of muscular ridges

additional structural support

rest of embryonic foramen ovale

- a conducted blood opening from R to LA in foetus, bypassing pulmonary circulation
- in **interatrial septum**, caudal to intervenous tubercle
- at birth, the foramen are closed, leaving depressed membranous **fossa ovalis** seen in mature heart

RIGHT VENTRICLE

right cranial portion of heart (forms most of cranial border)

receives blood from RA via **right atrioventricular (AV) valve**

inner surface has **trabeculae carnae** (muscular ridges) → reduce turbulence

RIGHT VENTRICLE (cont)

trabeculae septomarginalis or **moderator band** (muscular and fine fibrous strands) run between septum and ventricular wall

⇒ provide **structural support**, **conduct impulses** rapidly to entire ventricle, ensure **coordinated ventricular contraction**

Blood flow from RV into lungs

- RV is not fully separated by **supraventricular crest** (thin muscular ridge) → blood passes round the supraventricular crest, into **conus arteriosus** → pulmonary valve → pulmonary trunk → lungs

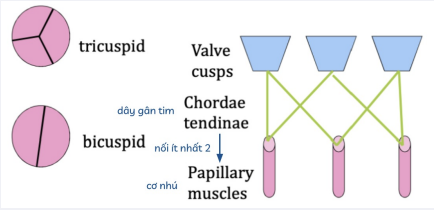
pulmonary valve

- 3 semilunar cusps

- fit tightly together when ventricle is relaxed

→ prevent blood backflow from pulmonary trunk into ventricle

HEART VALVES



▶ right AV valve has:
3 cusps (**tricuspid**) in most species
2 cusps (**bicuspid**) in dogs

THE CUSPS

▶ are anchored to fibrous skeleton of heart where it encircles AV opening

▶ free edges are attached by **chordae tendineae** (multiple fibrous strands) to **papillary muscles** (which project from ventricular wall)

- normally 3 papillary muscles
- each cusp attaches to 2 papillary muscles
- each papillary muscle anchors 2 cusps

RIGHT VENTRICLE - AV VALVE

separate atria from ventricles

ventricle contracts → papillary muscles contract → AV valve closes

→ prevents blood backflow into RA

▶ **blood passes from RV into pulmonary arteries**

thin-walled RV (pulmonary circulation has relatively low resistance to blood flow)

LEFT ATRIUM

dorso-caudal part of heart

oxygenated blood from lungs enters LA via 7-8 pulmonary veins

similar in general structure to RA

present pectinate muscles

valve of foramen ovale may be visible cranially in interatrial septum

LEFT VENTRICLE

left caudal portion of heart (forms caudal border)

conical - forms apex of heart

thick-walled → generate greater pressure to pump blood to body

blood from LA passes into LV via bicuspid **(mitral) left AV valve**

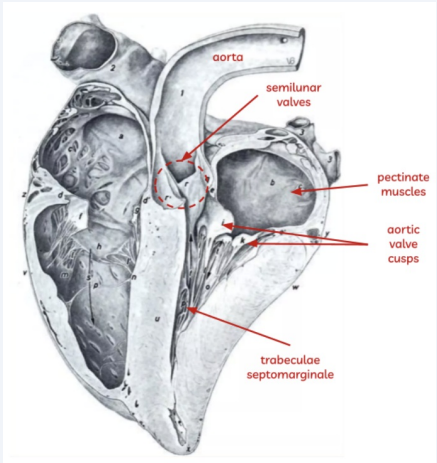
trabeculae carnae are more prominent, **papillary muscles** (usually 2) are larger, **trabeculae septomarginalis** also present

blood passes into aorta via **aortic valve**

- like pulmonary valve has 3 main semilunar cusps

- aorta distributes blood to body via its many branches

valve



valve

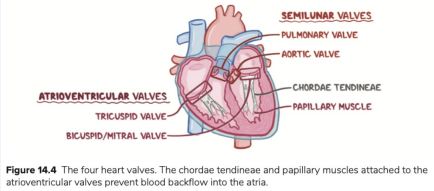
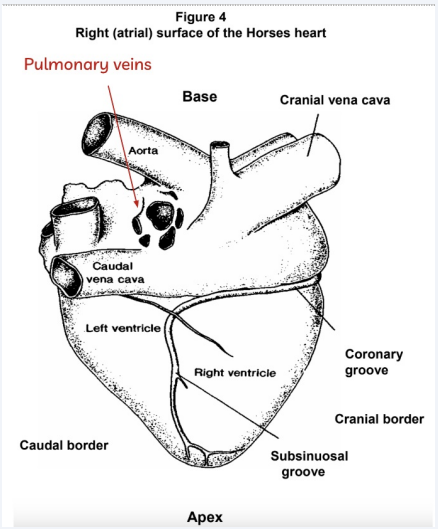


Figure 14.4 The four heart valves. The chordae tendineae and papillary muscles attached to the atrioventricular valves prevent blood backflow into the atria.

pulmonary veins



SKELETON OF THE HEART

annuli fibrosi

▶ fibrous skeleton

▶ rings of collagen and elastic fibers encircle right and left AV valves, aorta and pulmonary trunk

⇒ **separate** atria and ventricles; **structural support**

▶ anchor heart muscle ⇒ **prevent distortion of openings** during contraction

⇒ **prevent direct conduction of impulses** from atria to ventricles

▶ supporting bundles of collagen also pass down interventricular septum

fibrous trigone - a plate formed by dense fibrous skeleton between AV valves and base of aorta; composed of:

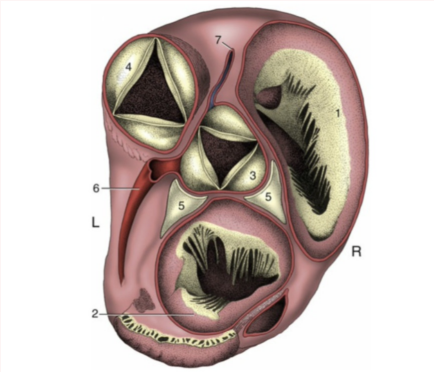
SKELETON OF THE HEART (cont)

- dense connective tissue (cat, pig)

- cartilaginous (dog, horse)

- partially ossifies → os cordis (ruminants, older individuals of other species)

Dorsal view



Dorsal view - the base of the bovine heart (removal of the atria)
1 Right atrioventricular valve (**tricuspid**) **2** left atrioventricular valve (**bicuspid**) **3** (aorta) aortic valve **4** conus arteriosus (pulmonary valve) **5** ossa cordis **6** left coronary artery **7** right coronary artery

FUNCTION ANATOMY OF HEART

⚲ deoxygenated blood enters relaxed RA via cranial and caudal venae cavae

coronary sinus (tiny RA opening) collects blood from coronary vessels → RA → right AV valve

▶ RA contracts ⇒ complete RV filling

▶ RV contracts ⇒ ↑ RV pressure → close right AV valve, open pulmonary valve → pulmonary valve → pulmonary trunk → lungs

▶ RV relaxes ⇒ ↓ RV pressure → close pulmonary valve (prevent backflow from lungs into RV))

opens right AV valve, right ventricular filling begins again

⚲ oxygenated blood from lungs enters LA via pulmonary veins

blood flows into LV via open left AV valve

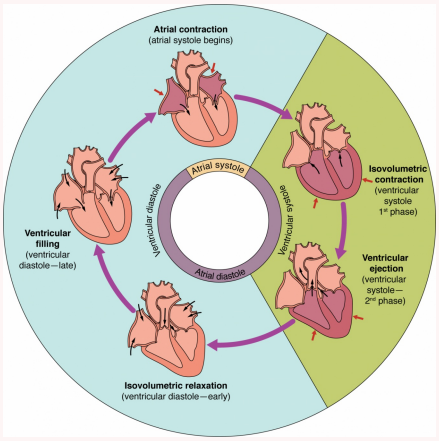
▶ LA contracts ⇒ complete ventricular filling

FUNCTION ANATOMY OF HEART (cont)

▶ LV contracts ⇒ ↑ LV pressure → closes left AV valve, opens aortic valve → aorta → rest of body

▶ LV relaxes ⇒ ↓ LV pressure → closes aortic valve (prevent backflow from aorta into LV)

CARDIAC CYCLE



systole is period of contraction, heart pumps the blood
diastole is period of relaxation, heart fills with blood

---

use a stethoscope to locate a valvular insufficiency or stenosis (heard as a "murmur" on auscultation)

PHASES OF CARDIAC WORK

atrial systole

- begin when atria, ventricles in diastole
- AV valves open → passive ventricular filling
- atrial depolarization → atria contract → completes ventricular filling
- ECG ▫ P wave, PR interval

isovolumetric contraction

- ventricular contraction begins (**ventricular systole**) → ventricular pressure > atrial pressure → **AV valves close** (**S1**); semilunar valves closed

PHASES OF CARDIAC WORK (cont)

- ECG ▫ QRS complex

rapid ejection

- ventricular systole continues → left ventricular pressure > aortic pressure → aortic valve open → blood ejected (SV) (blood also ejected into pulmonary vasculature via pulmonic valve)
- ↑ aortic pressure
- atrial filling begins
- ECG ▫ ST segment

reduced ejection

- ↓ ventricular ejection velocity
- ↑ atrial pressure
- ventricular repolarization begins
- ECG ▫ T wave

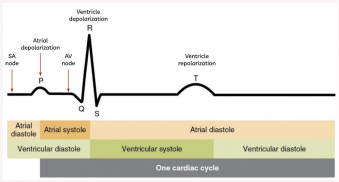
isovolumetric relaxation

- ventricles relaxed (**ventricular diastole**); ventricular pressure < aortic pressure → **aortic valve closes** (**S2**)
- all valves closed
- ventricular volume: constant
- complete ventricular repolarization
- ECG ▫ T wave ends

rapid ventricular filling

- ventricular diastole continues → ventricular pressure < atrial pressure → AV valves open
- passive ventricular filling

relationship between cardiac cycle and ECG



P wave - atrial depolarization
QRS complex - ventricular depolarization
T wave - ventricular repolarization

Pathway of electrical conduction

electrical impulse travels from **SA node**, goes through **atrial internodal fibers** to **AV node**

impulses continue down conduction pathway via **bundle of His** into **Purkinje fibers** → **ventricular myocytes**

trabeculae septomarginalis also carry Purkinje fibers to aid spread of electrical impulses to ventricles

POSITION OF THE VALVES

valve	side	position
pulmonary	left	3rd intercostal space at costochondral junction (above sternum)
aortic	left	4th intercostal space below shoulder joint (above costochondral junction)
left AV	left	4th - 5th intercostal space just below costochondral junction
right AV	right	3rd – 4th intercostal space at costochondral junction

SA node (sinoatrial node)

highest rate

pacemaker - generate heart beat

location: right atrial myocardium near junction with cranial vena cava

regulated by:

- **sympathetic cardiac nerve fibers** - ↑ discharge rate

- **right vagal (parasympathetic) nerve fibers** - ↓ discharge rate

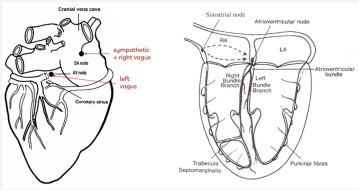
AV node (atrioventricular node)

second highest discharge rate

location: near coronary sinus on interatrial septum

mainly controlled by left vagus nerve

Location



COMPARATIVE HEARTS

CANINE

45° to sternum

apex lies on sternum at junction of sternum and diaphragm, attached to latter by **phrenicopericardial ligament**

right and left AV valves are bicuspid

EQUINE

further cranial and ventral (2nd to 6th intercostal space)

apex anchors to sternum by **sternopericardial ligament**

horses in training have a larger heart (hypertrophy vs hyperplasia)

RUMINANT

60% to left of midline (2nd to 5th intercostal space) - almost vertical

apex anchors to sternum by **sternopericardial ligament**

beware traumatic pericarditis

PORCINE

relatively small - (between 2nd to 5th ribs)

45° to sternum

HISTOLOGY OF HEART

ENDOCARDIUM

polygonal endothelial cells on basement membrane, supported by a **subendothelial coat** of fine collagenous and elastic fibers

MYOCARDIUM

cardiac muscle → **striated myocardial cells**, electrically coupled at **intercalated discs** (essential for rhythmic contraction)

HISTOLOGY OF HEART (cont)

form branching and anastomosing fibers

perinuclear halo - pale staining cytoplasm surrounds cardiac muscle nuclei (central nucleus)

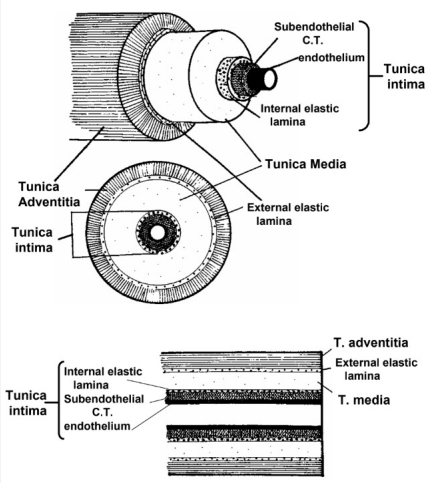
endomysium - connective tissue sheath surrounds each muscle fiber, thickened at valve attachment points and fibrous skeleton

EPICARDIUM

serous membrane - forms the visceral pericardium

carries vasculature

HISTORY OF BLOOD VESSELS



▶ 3 layers: tunica adventitia, tunica media, tunica intima

- external connective tissue
- **tunica adventitia** (most important)
  + external elastic lamina
- **tunica media**
- **tunica intima**
  + internal elastic lamina
  + subendothelial connective tissue
  + endothelium
- lumen

HISTORY OF BLOOD VESSELS - ARTERY

CONDUCTING (ELASTIC) ARTERIES

large arteries, wide lumen → conduct large volumes of blood around body

- *tunica intima* - all elements present

- *tunica media* - mostly elastic fibers, but fine collagen fibers, fibroblasts, smooth muscle in between

- *tunica adventitia* - no distinct external elastic lamina, blend with surrounding tissue

DISTRIBUTING (MUSCULAR) ARTERIES

small and medium sized arteries, carry blood to specific tissues

very thick wall → smaller lumen

3 layers are present

- elastic laminae well-defined

- tunica media mainly has a thick layer of smooth muscle

ARTERIOLES

lumen diameter < 200μm

- *tunica intima* - lacks subendothelial coat

- *tunica media* - has only 1-3 layers of smooth muscle cells

- *tunica adventitia* - no external elastic lamina, connective tissue blends with surrounding tissue

HISTORY OF BLOOD VESSELS - CAPPILARIES

- exchange site of metabolites and waste products

- diameter < 10μm → allow to pass single blood cells

- endothelial cells line basement membrane - surrounded by loose connective tissue

- 5 types

CONTINUOUS CAPILLARIES

- no pores or interruptions between endothelial cells

- muscle, lungs, nervous tissue

FENESTRATED CAPILLARIES

HISTORY OF BLOOD VESSELS - CAPPILARIES (cont)

- have pores throughout endothelial walls
- endocrine glands, intestines, where fluid transport is important

SINUSOIDAL CAPILLARIES

- larger, more irregular shaped, no distinct basement membrane
- endocrine organs, aortic and carotid bodies

SINUSOID

- larger, basement membrane mostly absent, gaps in walls → exchange large molecules (proteins)
- bone marrow, liver

SINUSES

- larger than sinusoids with a discontinuous basement membrane
- spleen

HISTORY OF BLOOD VESSELS - VEIN

VENULES

- lined by endothelial cells combined with loose connective tissue

SMALL AND MEDIUM VEINS

- more smooth muscle, less muscular than similarly-sized arteries
- thin *tunica intima* and *tunica media*, surrounded by well-developed *tunica adventitia*
- may have valves formed by invaginations of the tunica intima → ensure blood flows in one direction

LARGE VEINS

- *tunica intima* - thicker, may be internal elastic lamina
- *tunica media* - mainly collagen and elastic fibers (may have smooth muscle)
- *tunica adventitia* - thickest, has fibroelastic tissue. No valves in largest veins

FUNCTIONAL ANATOMY OF BLOOD VESSELS

- **store kinetic energy** by elastic artery during systole
- **maintain blood pressure and blood flow** by elastic fibers recoil in diastole
- **regulate blood supply** by autonomic control of smooth muscle
- **provide resistance to pulse pressure** for capillaries by arterioles
- **exchange site** (capillaries)

VENOUS RETURN

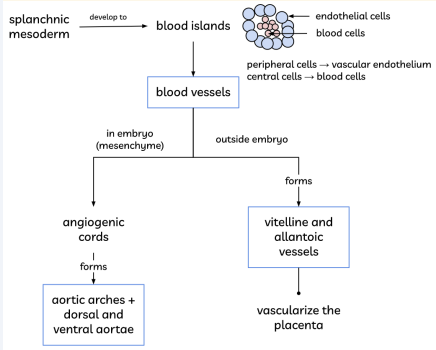
is aided by:

▶ **muscular pump** - limb muscles contract → external pressure on large veins

▶ **respiratory pump** - (-) pressure (during inspiration) in thorax helps return blood to heart

▶ **cardiac pump** - low (+) blood pressure (~ 15mmHg) in great veins returns to heart

HAEMATOPOIESIS AND ANGIOGENESIS



haematopoiesis - sự tạo huyết
angiogenesis - sự tạo mạch

splanchnic mesoderm: trung bì tạng
peripheral cells: tế bào ngoại vi
vascular endothelium: nội mô mạch
embryo: phôi
vitelline: noãn hoàng
allantoic: nang
vascularize: tạo mạch máu
placenta: nhau thai
mesenchyme: trung mô
cord: sợi
arch: vòm

COMPARATIVE ANATOMY OF AORTIC ARCHES

aortic arches

▶ 6 pairs, enclose pharynx

▶ ventral aorta to dorsal aorta

▶ fish

- all 6 pairs may be functional

▶ birds and mammals

- aortic arches I,II,V degenerate

- aortic arches III, IV and VI remain

SPECIALIZED CARDIOVASCULAR ELEMENTS

▶ **collateral circulation**

- most **distributing arteries branches** before ending in tissues

- lung, intestine

▶ **anatomical end artery**

- no anastomosis exists

- single artery supplies blood to a specific tissue piece with no collateral circulation

- brain, cornea

▶ **functional end artery**

- anastomosis exists but not give enough blood

- artery supplies blood to a specific tissue piece has insufficient collateral circulation

- coronary, cerebral and retina arteries

▶ **retia mirabilia**

- major arteries which split suddenly into multiple parallel vessels

renal glomerulus

▶ **arteriovenous anastomosis**

- blood shunts directly from an arteriole to a venule, bypassing capillary bed

- skin, horse hoof

▶ **vasa vasorum**

SPECIALIZED CARDIOVASCULAR ELEMENTS (cont)

- a fine network of vessels, supply walls of major blood vessels

- in tunica adventitia / external tunica media

▶ **portal systems**

- a vein connects 2 capillary beds

- hepatic portal system

- hypothalamo-hypophyseal portal system

▶ **alternative venous drainage**

- some tissues are drained by two venous routes

- bronchial, caudal vertebral column

▶ **veins without valves**

- some specially large veins lack valves

- vertebral venous sinus, portal veins

BRONCHIAL CIRCULATION

lungs have **dual circulation** between **broncho-esophageal** and **pulmonary**

in pigs, carnivore, some ruminants, some blood from bronchi drains via brochial veins → azygous vein → enters RA

remaining bronchial blood, all of it in horse, returns to heart via oxygenated pulmonary vein → LA

CORONARY CIRCULATION

▶ coronary arteries - **first branches** of aorta

▶ left and right coronary arteries

- not form collateral circulations

- functional end arteries supply myocardial capillary bed

LCA supplies left heart chambers

RCA supplies right heart chambers

▶ considerable species variation

▶ venous drainage from myocardial capillary bed

- great coronary vein → RA (at coronary sinus)

small coronary vein (Thebesian veins) → into all 4 chambers

CORONARY CIRCULATION (cont)

Carnivore and ruminant

- LCA supplies paraconal and subsinuosal interventricular branches and left circumflex branch

- RCA supplies right circumflex branch

horse and pig

- LCA supplies paraconal interventricular branch

- RCA forms right circumflex branch, and subsinuosal interventricular branch

THE CONDUCTION SYSTEM

cardiac muscle fibers **contracts on its own** without external stimulus

origin of heart beat from **muscular (myogenic)**, not neural (neurogenic)

innervation of myocardium

- response to change

- from both sympathetic and parasympathetic stimuli

- concentrated around nodes

CONGENITAL CARDIOVASCULAR PROBLEMS

các vấn đề tim mạch bẩm sinh

SEPTAL DEFECTS (*dị tật vách ngăn*)

▶ Atrial

foramen ovale can not close → ↑ load on right side (higher left atrial pressure)

→ pulmonary congestion and relative pulmonic stenosis

▶ Ventricular

↑ pulmonary blood flow, and left ventricular dilatation and failure

PATENT DUCTUS ARTERIOSUS (*còn ống động mạch*)

▶ blood flow from right to left cause pulmonary vascular resistance and right heart pressures decrease, left heart pressures increase

→ pulmonary congestion and machinery murmur

VALVULAR DEFORMITIES (*dị dạng van tim*)

CONGENITAL CARDIOVASCULAR PROBLEMS (cont)

▶ **stenosis** (*hẹp van tim*)

pulmonic stenosis → right ventricular hypertrophy and failure → "sea-gull" murmur

aortic stenosis → poor coronary blood supply → sudden death, myocardial damage

▶ **incompetencies** (leakage or insufficiency) (*hở van tim*)

common in AV valve → blood backflow

TETRALOGY OF FALLOT (*tứ chứng Fallot*)

4 problems:

- ventricular septal defect

- pulmonic stenosis

- aortic override

right ventricular hypertrophy

→ stunting and cyanosis

VASCULAR RING ANOMALY (Persistent Right Aortic Arch)

abormal development of aortic arch → form constricting band around esophagus → megaesophagus

PORTOSYSTEMIC SHUNTS

anastomosis forms between portal system and any of main veins

toxic metabolic products from gut to bypass liver, go directly to heart →

→ animal can't grow → hepatic encephalopathy (damage to brain tissues)