Veterinary Bioscience 1: Cardiovascular System

Lecture 2 – The heart within the thorax

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Intended Learning Outcomes

At the end of this lecture you should be able to:

- Apply an understanding of the position of the heart within the thoracic cavity and its relationship to other structures, in order to determine the major features of the heart visible on standard radiographic views.
- Apply an understanding of the relationship between the internal and external features of the heart, in order to relate this to cardiac function.
- Utilise your knowledge of the relationship between the major systemic arteries and the heart, plus other structures in the thorax, in order to demonstrate the route of blood flow to the head, forelimbs, lungs, thoracic wall and abdomen.

THE THORAX BODY REGION

The thoracic body region is the cranial portion of the trunk between the neck cranially, and the abdomen caudally, and with the forelimbs extending laterally and ventrally from its cranial portion. It is in the form of a laterally flattened, truncated cone – the smaller end facing cranial and the larger one caudal. It is basically an expansible container, the thoracic cavity lying within, housing the major organs of the cardiovascular and respiratory systems – its regular excursions being essential for normal respiration. The cranial opening of this cavity is the thoracic inlet, which is bounded laterally by the first ribs and through which passes the trachea, oesophagus and several major vessels and nerves. The caudal opening, the thoracic outlet, is bounded laterally by the costal arches and is closed by a musculotendinous sheet - the diaphragm.

The thoracic region's boundaries are readily appreciated externally by several bony structures associated with its skeleton - the thoracic vertebrae, ribs and sternum. The first thoracic vertebra (its spinous process is palpable), the first ribs and manubrium mark the cranial boundary. The 13th thoracic vertebra (its spinous process is palpable), the costal arch and the xiphoid cartilage mark the caudal boundary. Its internal boundaries vary from these due to the cranially directed convexity of the diaphragm such that some abdominal organs lie cranial to the costal arch.

THE HEART

SEE TABLE OF COMPARATIVE CHARACTERISTICS OF THE HEART (Addendum notes 1)

The heart accounts for **about 0.6% of total body weight** in most normal domestic animals.

Exceptions: Greyhound and Thoroughbred horse - almost twice the average level and can be increased further by athletic training. Pig is usually 0.3% of total body weight there is a suggestion that this is a factor in "sudden death syndrome" in this species.

POSITION OF THE HEART:

L**ies in the mediastinum** (the partition between right and left pleural cavities) enclosed within its pericardial sac.

Usually situated **between the third and sixth ribs** (this area of lateral thoracic wall is largely covered by the triceps muscle of the forelimb).

Dorsal boundary - lies on a **horizontal plane through the centre of the first rib**

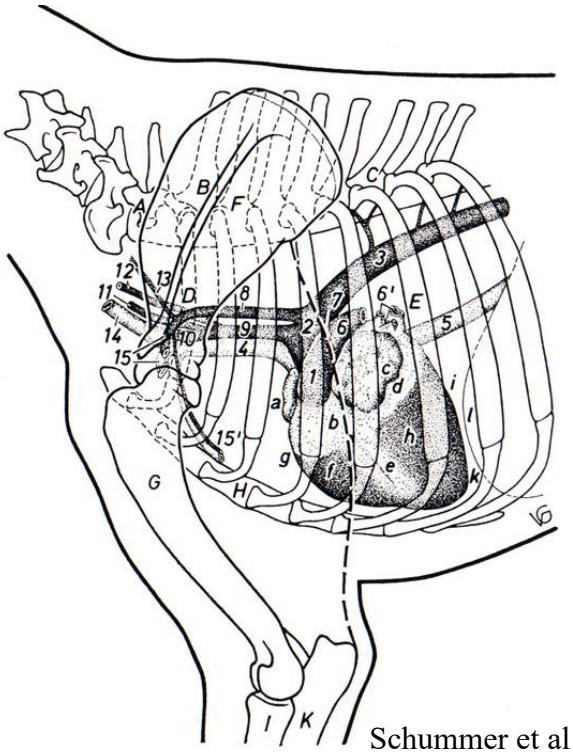
Caudal boundary - is the **dome of the diaphragm**

Ventral boundary - is the **sternum**

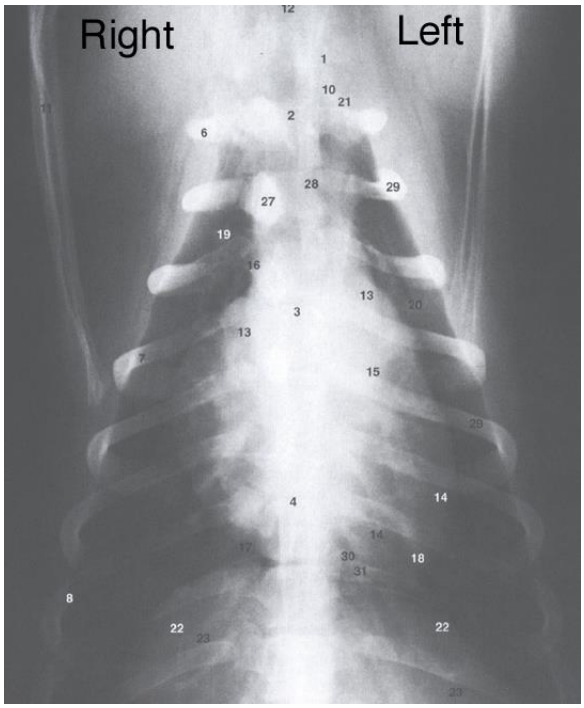
Right lung is larger than the left - therefore **most of the heart lies to left of the mid-line** - and **left surface of heart is nearer to the thoracic wall than the right.**

The **long axis of heart** is: essentially vertical in the horse,
almost vertical in ruminants,
progressively more oblique in the pig, dog and cat.

SEE SHEET FOR COMPARATIVE ANATOMY OF THE HEART AS IT RELATES TO PHYSICAL EXAMINATION (Addendum Notes 2).



Schummer et al 1981



Boyd et al 200

SHAPE OF THE HEART:

Cone shaped - slightly flattened on left and right sides, to conform to the similar compression of the thorax.
Base of the heart - most dorsal part of heart - low dome **formed by** the **left and right atria.**
Great veins - systemic and pulmonary - **enter the base of the heart**
Great arteries - aortic and pulmonary **- emerge from the base of the heart.**
The heart is held in position by the great vessels but otherwise lies entirely free within the pericardium (pericardial sac).

Apex of the heart - tapered portion of the cone, formed by the left ventricle, lies close to the sternum.
Long axis of heart - extends from middle of the base to the apex.
Cranial aspect - extensively related to thymus in the young animal.
Right and left lateral surfaces face the corresponding lungs.
Caudal border faces towards the diaphragm - thus may be directly related to the cranial abdominal organs

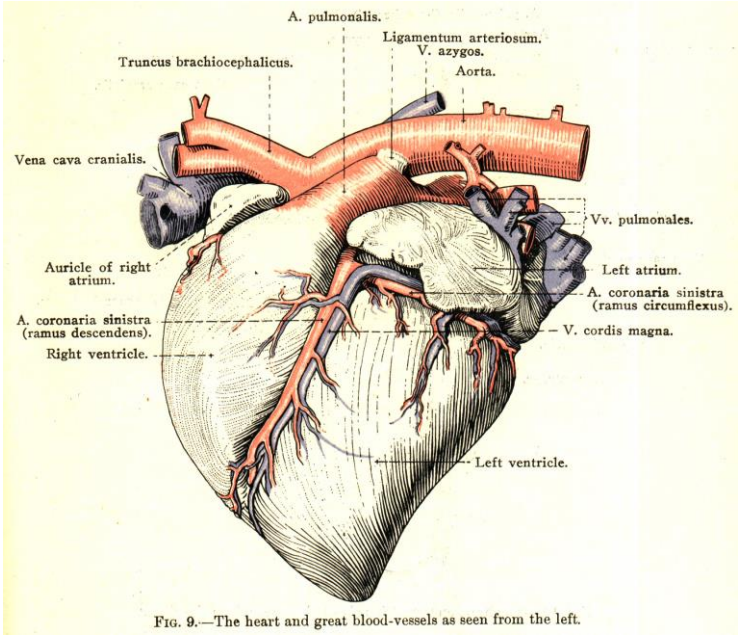


FIG. 9.—The heart and great blood-vessels as seen from the left.

Bradley 1922.

THE PERICARDIUM

A serous sac deeply invaginated by the heart. The sac is closed and its lining is a simple squamous (flat) mesothelium. (Mesothelium: epithelial-like cells derived from embryonic mesoderm).
The Functions of the pericardium are to form a protective sac around the heart, to help maintain the heart in position, to help minimise friction and perhaps may have a role in preventing the heart from becoming over distended. The **Pericardial cavity** is occupied by a thin film of serous fluid - lubricant – which enables visceral and parietal layers of pericardial membrane to slide over each other during the cardiac cycle.

Layers of the wall of the pericardium:
Visceral pericardium - inner wall of the pericardial sac, coats the outer surface of the heart
Parietal pericardium - at the neck of the sac the visceral pericardium continues onto the outer wall of the sac. The external surface of the parietal pericardium is reinforced by a strong layer of fibroelastic tissue. This layer is called the fibrous pericardium.

Dorsally the fibrous layer of the parietal pericardium continues over the great vessels.
Ventrally the fibrous pericardium continues on and attaches to the sternum in:
Ruminants – as paired sternopericardiac ligaments
Horse – as a single midline sternopericardiac ligament

In carnivores and the pig, it attaches to the diaphragm – as the **phrenico-pericardiac ligament**

These **ligaments anchor the pericardium in position ventrally and caudally.**

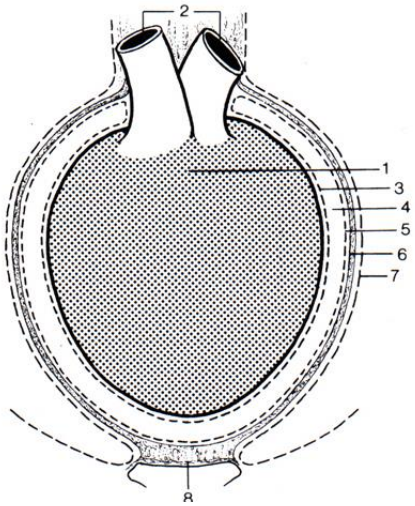


Figure 7–5. Schematic illustration of the pericardium.

1, Heart; 2, great vessels; 3, visceral pericardium (epicardium); 4, pericardial cavity (exaggerated in size); 5, parietal pericardium; 6, connective tissue layer of the parietal pericardium; 7, mediastinal pleura; 8, sternopericardial ligament.

Dyce et al 2002

Relationship to thoracic wall
The Cardiac notch is the gap in the ventral border of left and right lungs, which allows the pericardium to make contact with the thoracic wall. This is greater on left side, and provides a useful 'acoustic window' for echocardiography.

Pericardial cavity
Occupied by a thin film of serous fluid - lubricant – which enables visceral and parietal layers of pericardial membrane to slide over each other during the cardiac cycle

In disease - excessive fluid in pericardial sac - results in compression of heart (cardiac tamponade) - prevents dilation and filling of heart chambers, impedes return of flow to the heart and results in distension of peripheral veins, eg the external jugular

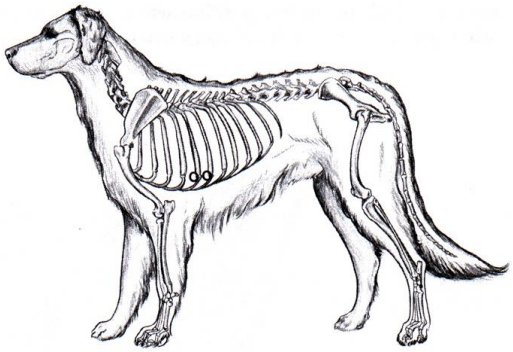


Figure 22-2 Sites for performing pericardiocentesis.

Functions of the pericardium:
To form a **protective** sac around the heart
To help **maintain the heart in position**
To help **minimise friction**
Perhaps has a role in preventing the heart from becoming over distended.

EXTERNAL FEATURES OF THE HEART

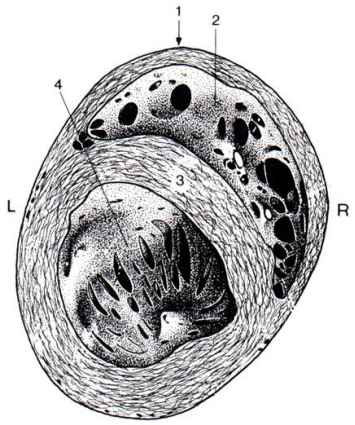
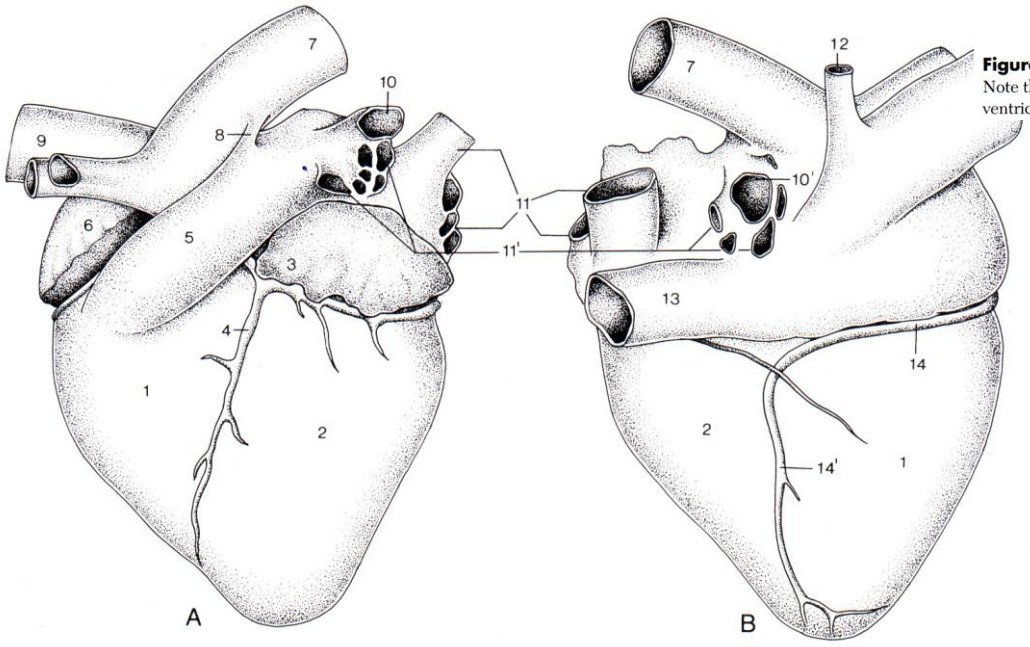


Figure 7–10. Transverse section through the ventricles Note the different thicknesses of the walls of the right and lef ventricles.



Dyce et al 2002

Figure 7–7. Left *(A)* and right *(B)* views of the equine heart.

1, Right ventricle; 2, left ventricle; 3, left auricle; 4, paraconal interventricular branch of left coronary artery; 5, pulmonary trunk; 6, right auricle; 7, aorta; 8, ligamentum arteriosum; 9, cranial vena cava; 10, 10′, left and right pulmonary arteries; 11, 11′, left and right pulmonary veins; 12, right azygous vein; 13, caudal vena cava; 14, right coronary artery; 14′, subsinuosal interventricular branch of right coronary artery.

The base of the heart is formed by the **thin walled atria** - separated from the ventricles by the encircling **coronary groove**.

Each atrium has **a blind diverticulum** (or free appendage) called the **auricle.**

The thicker walled left and right ventricles fuse together to form a firm cone. The position of the **interventricular septum** (wall dividing the left and right internal chambers of ventricle) is marked externally by the Left interventricular (or paraconal) groove on left side of the heart and the right interventricular (or subsinuosal) groove on the right side of the heart.

The left surface of heart (or auricular surface) is formed mainly by the left atrium and left ventricle**,** but the right ventricle and right auricle extend round the cranial border of the heart - contributing substantially to the left surface.

The **right surface (or atrial surface)** is formed mainly by the right atrium and right ventricle**,** but the left ventricle extends around the caudal border of the heart - contributing to the right surface.

The **right ventricle lies as much cranially as to the right of the left ventricle**
Cranial border of right ventricle is convex
Caudal border of left ventricle is: slightly convex in domestic carnivores
almost straight and vertical in the horse
slightly concave in ruminants (follows contour of diaphragm)

INTERNAL FEATURES OF THE HEART

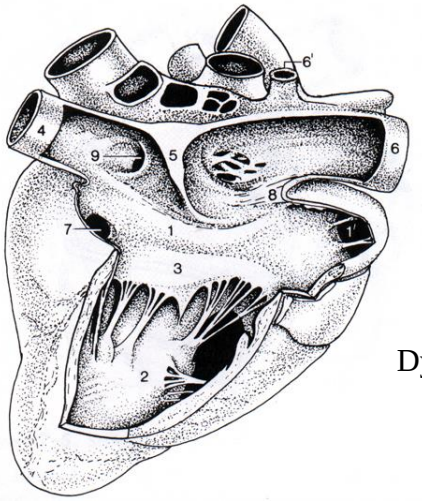


Figure 7–8. Overview of the interior of the right atrium and right ventricle of the equine heart.

1, Right atrium; 1′, right auricle; 2, right ventricle; 3, right atrioventricular valve; 4, caudal vena cava; 5, intervenous tubercle; 6, cranial vena cava; 6′, right azygous vein; 7, coronary sinus; 8, terminal crest; 9, fossa ovalis.

Dyce et al 2002

The **right atrium** forms a chamber into which the principal systemic veins discharge.

In all domestic species the **right atrium has four main openings**:

1. The **cranial vena cava** - drains the head, neck, forelimbs, ventral thoracic wall and the adjacent part of the abdominal wall
2. The **caudal vena cava** - drains blood from the abdominal viscera, part of the abdominal wall and the hindlimbs
3. The **coronary sinus** - returns venous blood from the heart itself, opening immediately ventral to the opening of the caudal vena cava
4. Right **atrioventricular (A-V) orifice** - guarded by the right A-V valve - transfers venous blood from R. atrium to the R. ventricle

Azygous veins drain blood from part of the lumbar region, caudal 3/4 of the thoracic wall and the venous drainage of the bronchial circulation and oesophagus.
Right azygous vein only - occurs in **carnivores, horse and sometimes the pig**
enters cranial vena cava near the R. atrium or opens directly into the roof of the R. atrium.
Left azygous vein only - **usually occurs in the pig** - opens into the coronary sinus
Left and Right azygous veins are **usually present in ruminants**

Small coronary veins open directly through the atrial wall via numerous small foramina

The **Right auricle** – a blind diverticulum - opens from the cranial end of the right atrium and winds around the cranial aspect of the heart

The **internal wall of** atrium is smooth, but the auricle is interlaced with muscular ridges, the **pectinate muscles.** Some vestiges of the foetal circulation are also present in the right atrium (see later lecture):

- the **fossa ovalis** - an oval depression on the interatrial septum at the opening of the caudal vena cava
- **intervenous ridge (or intervenous tubercle**) - a transverse arch projecting from the dorsal wall of the atrium, between cranial and caudal venae cavae; directs blood from the cranial vena cava into the ventricle
- **crista terminalis** - muscular ridge on the internal surface of the right atrium - most of the pectinate muscles radiate from the crista terminalis

The **Right Ventricle** receives blood from the right atrium and **pumps blood into the pulmonary trunk.** A thick muscular interventricular septum separates the right and left ventricles. The **lumen is crescent shaped in transverse section and its** opening is guarded by the **right atrioventricular (or tricuspid) valve.**

Valve cusps are composed of a **layer of collagen fibres sandwiched between two layers of endothelium**; the collagen fibres are continuous with those of the fibrous ring that surrounds the right A-V opening.

Chordae tendineae - arise from **papillary muscles** that project from the internal surface of the ventricular wall and fan out to attach to the cusps of the A-V valve. Each papillary muscle modulates the movements of two cusps.

Right septomarginal trabeculae (or **moderator band**) - rounded bundle of tissue crosses the lumen of the ventricle from the interventricular septum to the lateral wall. Several smaller bundles tend to pass from the interventricular septum to the base of the papillary muscles. They distribute conducting fibres to the papillary muscles

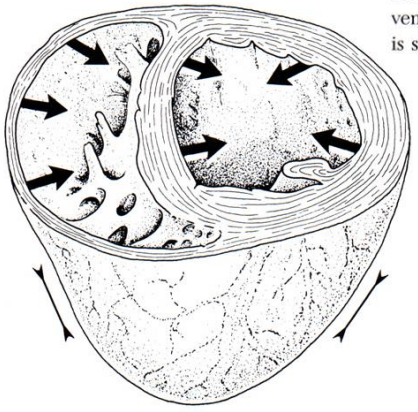


Figure 7–19. Schematic drawing of the mode of contraction of the left and right ventricles. The wall of the left ventricle contracts radially, while the right ventricular lumen is squeezed in a "bellows" action.

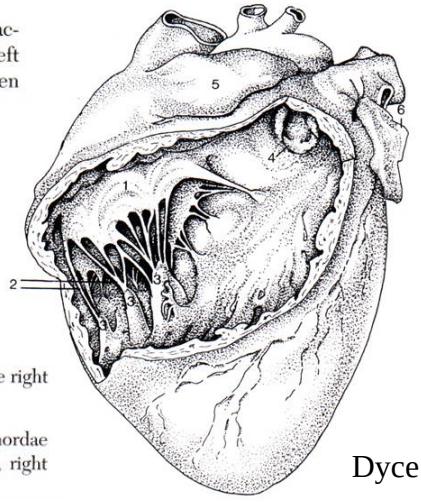


Figure 7–12. Cranioventral view of the interior of the right ventricle.

1, Cusp of right atrioventricular valve; 2, chordae tendineae; 3, papillary muscles; 4, pulmonary valve; 5, right auricle; 6, left auricle.

Dyce et al 2002

The **Ventricular cavity** is divided into two functional components - an **inflow channel** and an **outflow channel**. Since the pulmonary circulation is a low pressure system, the wall of the right ventricle need only be about half as thick as that of the left ventricle**.**

The inflow channel - extends from the right A-V opening into the ventricle to about the level of the septomarginal trabeculae. The surface is rendered irregular by the **trabeculae carneae** (subendocardial myocardial ridges on the ventricular wall that protrude into the lumen) and by the presence of the **papillary muscles.**

Right ventricle has **three papillary muscles:** two arise from the interventricular septum. A third, larger papillary muscle - **the great papillary muscle** - arises from the outer (parietal) wall of the ventricle.

The outflow channel - starts at the septomarginal trabeculae and consist mainly of the funnel-shaped **'conus arteriosus'** that **directs blood into the pulmonary trunk**. The conus arteriosus has no papillary muscles and no trabeculae carneae - **smooth walls.** Note: Similar considerations apply to the left ventricle inflow and outflow channels.

Root of the pulmonary trunk - slightly increased in diameter in the region of the **pulmonary valve** - three semilunar valvules form three pockets; each valvule has a slightly thickened free border, with a small nodule on the midpoint; the structure of the valvule is similar in principle to that of an atrioventricular cusp.

The **sinuses of the pulmonary trunk** - three bulges in the wall of the trunk, corresponding to the three semilunar valvules; These sinuses resemble the three sinuses of the aortic bulb but are less distinct.

The **thick muscular interventricular septum** has two components: The larger muscular part is thick myocardium formed by the combined walls of the two ventricles. The collagenous but thin membranous part is a small inconspicuous area in the extreme dorsal part of the septum.

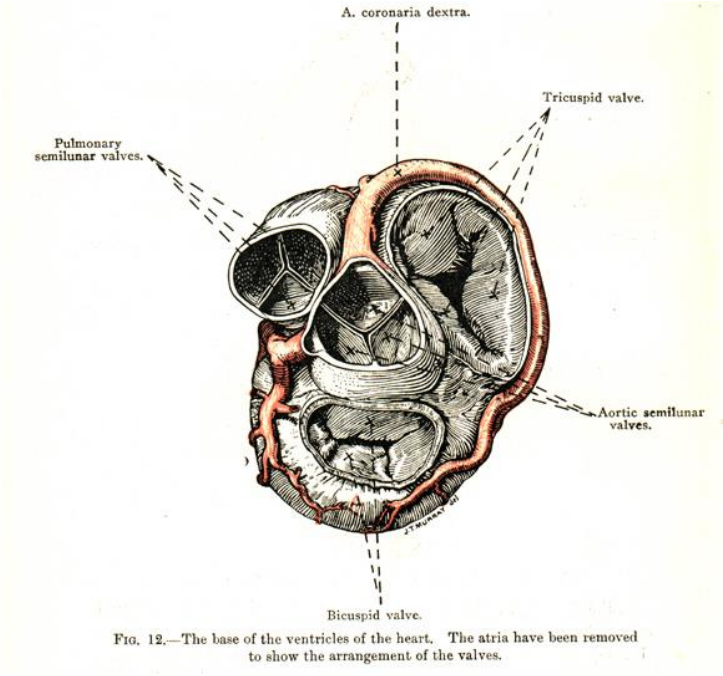


FIG. 12.—The base of the ventricles of the heart. The atria have been removed to show the arrangement of the valves.

Bradley 1922

The Left atrium receives arterial blood from the lungs via the pulmonary veins. As in the right atrium, small coronary veins also empty into the left atrium. The **Left auricle** is a blind diverticulum with pectinate muscles present on internal surface; the rest of the atrium has a smooth internal wall.

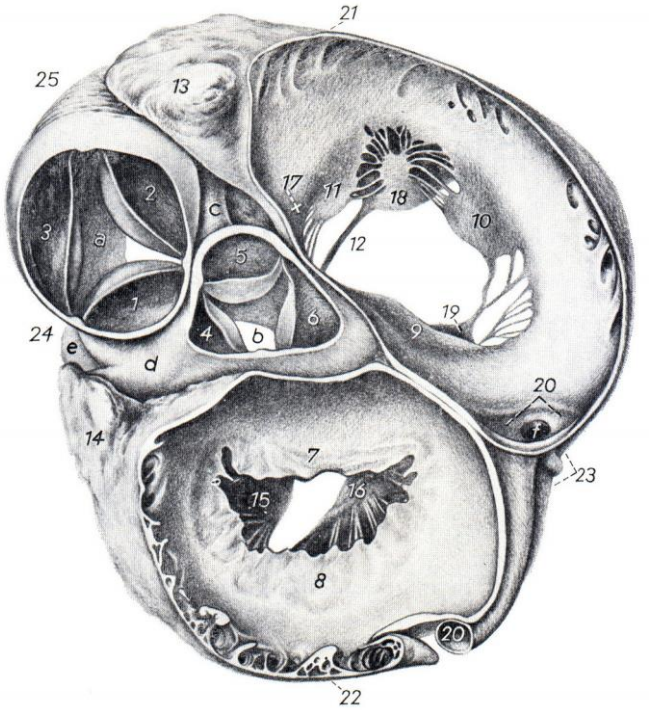


Fig. 13. Base of the bovine heart. The ventricles, atria and in part also the aorta and pulmonary trunk have been removed close to their origin. Basal aspect. (After Preuss, 1955.)

a ostium trunci pulmonalis; *b* ostium aortae; *c* a. coronaria dext.; *d* a. coronaria sin.; *e* r. interventricularis paraconalis of the v. cordis magna; *f* v. cordis media s. interventricularis subsinuosa

1, 2, 3 valva trunci pulmonalis, *1* its valvula semilunaris sin., *2* dext. and *3* intermedia; *4, 5, 6* valva aortae, *4* its valvula semilunaris sin., *5* dext and *6* septalis; *7, 8* valva atrioventricularis sin. s. bicuspidalis (mitralis), *7* its cuspis septalis and *8* parietalis; *9, 10, 11* valva atrioventricularis dext. s. tricuspidalis, *9* its cuspis septalis, *10* parietalis and *11* angularis; *12* trabecula septomarginalis; *13* auricula dext.; *14* auricula sin.; *15* m. papillaris subauricularis; *16* m. papillaris subatrialis of the left ventricle; *17* position of the m. papillaris subarteriosus; *18* m. papillaris magnus; *19* mm. papillares parvi of the right ventricle; *20, 20* sinus coronarius; *21* margo ventricularis dext.; *22* margo ventricularis sin.; *23* sulcus interventricularis subsinuosus; *24* sulcus interventricularis paraconalis; *25* conus arteriosus

Schummer et al 1981

The **Left ventricle** is connected to the left atrium via the left A-V opening, guarded by **the left atrioventricular (or mitral) valve.** This has two cusps, and is also known as the bicuspid valve. As the systemic circulation is a high pressure system, therefore the wall of the left ventricle is about 2 or even 3 times as thick as the right ventricle.

The Left atrium connects to the left ventricle via the left A-V opening.
The opening is guarded by **the left atrioventricular (or mitral) valve.**
Mitral valve has two cusps. It is also known as the bicuspid valve.
General structure and relationships between the cusps, chordae tendineae, and papillary muscles of the left A-V valve are the same, in principle, as for the right A-V valve.
As in the right ventricle there is the **same number of cusps as papillary muscles** (**two in the left**) and each muscle shares two cusps. Both papillary muscles in the left ventricle arise from the outer wall of the left ventricle.

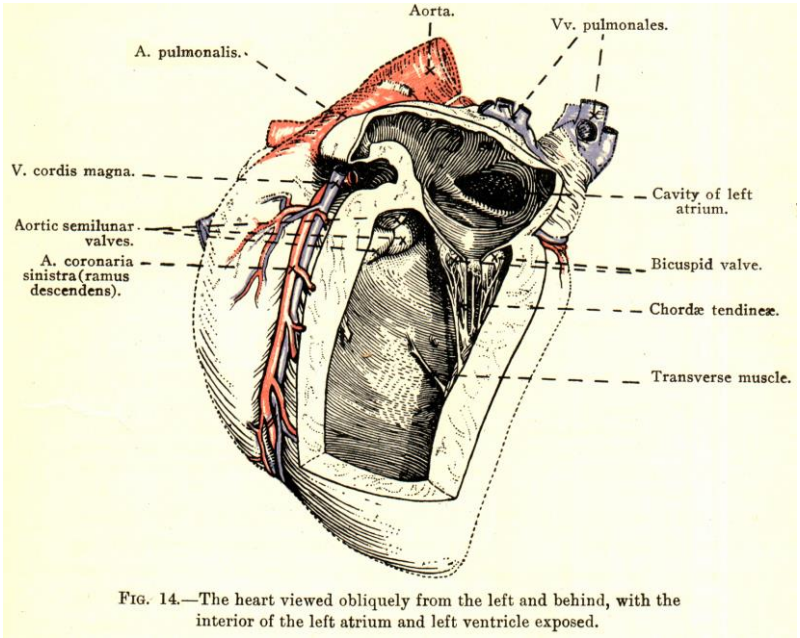


Fig. 14.—The heart viewed obliquely from the left and behind, with the interior of the left atrium and left ventricle exposed.

Bradley 1922

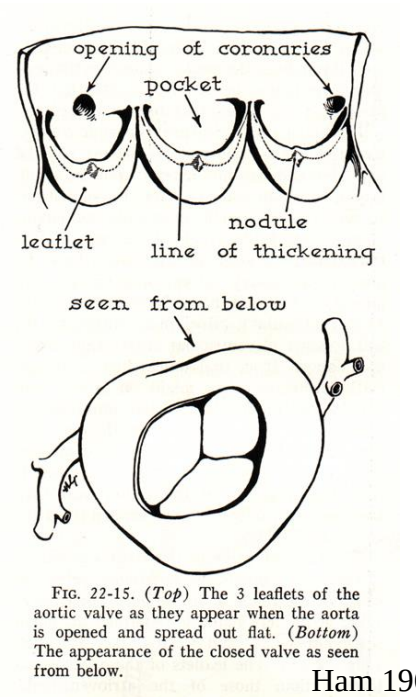


Fig. 22-15. (*Top*) The 3 leaflets of the aortic valve as they appear when the aorta is opened and spread out flat. (*Bottom*) The appearance of the closed valve as seen from below.

Ham 1969

Like the pulmonary valve the **aortic valve** consists of three semilunar valvules.

The root of the aorta at the site of the aortic valve is expanded into the aortic bulb by three bulges, the **aortic sinuses**. These correspond to the position of the three semilunar valvules.

Left coronary artery opens from the left aortic sinus, the **right coronary artery** opens from the right aortic sinus, the remaining sinus is referred to as the septal aortic sinus.

Note – the **systemic circulation is a high pressure system,** therefore the **wall of the left ventricle is about 2 or even 3 times as thick as the right ventricle.**

Similarly cusps of the left A-V valve and the semilunar valvules of the aortic valve are much stronger and thicker than those of the right side of the heart.

As in the right ventricle, one large **trabeculae septomarginalis** and several smaller ones traverse the ventricular lumen from the interventricular septum to the base of the papillary muscles on the lateral wall.

As in the right ventricle, the outflow channel of the left ventricle is smooth, however, the walls of the inflow channel are very irregular because of the presence of very strong trabeculae carneae, as well as prominent papillary muscles.

The **thick muscular interventricular septum** has two components:

- The larger muscular part is thick myocardium formed by the combined walls of the two ventricles. The surface facing into the lumen of the left ventricle is concave, whereas the surface facing into the lumen of the right ventricle is convex.
- The collagenous but thin membranous part is a small inconspicuous area in the extreme dorsal part of the septum. It marks the site of final closure of the embryonic interventricular foramen. This septum is the site of congenital interventricular defects, which are reported to be one of the commonest cardiac malformations in domestic animals, especially cattle.

HEART WALL STRUCTURE

The **thick middle layer of the wall of the heart - the myocardium -** is composed of cardiac muscle. This is a variety of striated muscle peculiar to the heart.

The heart wall is **covered externally by the visceral pericardium** (**epicardium)** and internally by the **endocardium,** a thin smooth-surfaced layer continuous with the lining of the blood vessels.

The cardiac muscles of the atria and ventricles are completely separated by a fibrous skeleton (This is essential for preventing widespread electrical conduction between atria and ventricles, and will be discussed in the later lecture on electrical activity in the heart).

Atrial muscle is thin and is arranged in superficial and deep bundles. Some of the superficial bundles are common to both atria, but the remainder of the superficial and all of the deep bundles are confined to individual atria.

The **ventricular muscle is much thicker**, but is also arranged in superficial and deep bundles. Some superficial bundles coil around both chambers, utilising the septum to complete a figure-of-eight course. Others, like the deeper bundles, encircle only the one chamber. The arrangement of the muscle is actually very complicated and rather obscure.

MAJOR SYSTEMIC ARTERIES

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Aorta – the main systemic arterial trunk - distributes oxygenated blood to the various regions of the body.

Arises from the left ventricle, and is **divided into 3 main segments:**

1. **Ascending aorta**
2. **Aortic arch**
3. **Descending aorta**

The **ascending aorta** -

Is **very short** (~ 2 cm in length). **Arises from the left ventricle** and **passes dorsally and cranially between the pulmonary trunk on its left and the right atrium to its right. Supplies blood to the wall of the heart.**

The left coronary artery originates from the left aortic sinus and the right coronary artery originates from the right aortic sinus.

The **aortic arch** -

Starts when the aorta makes a u-turn dorso-caudally, penetrating the pericardium and ascending within the mediastinum to reach the left ventral aspect of the 7th thoracic vertebrae. Supplies blood to the head, neck, base of neck, shoulder, forelimbs and thoracic wall.

The **descending aorta** - **Extends caudally along the dorsal body wall.**

Is divided into: The **thoracic part** supplies blood to **– the thoracic wall** and **internal organs of the thorax.**

The **abdominal part** supplies blood to – **the abdominal wall, abdominal organs, hindlimbs.**

The descending aorta terminates by giving rise to the left and right internal iliac arteries - supply blood to the pelvic wall and pelvic organs. Also median sacral artery - supplies the tail.

MAJOR BRANCHES OF THE AORTA WITHIN THE THORAX

The aortic arch - 1 to 3 major vessels arise directly from the aortic arch.
Subject to species variation. Prototype species - the **dog**.

TWO major vessels arise from the aortic arch:

The **brachiocephalic trunk**.

The **left subclavian artery.**

These vessels give rise to branches which supply the head neck, thorax and the thoracic limbs.

The **brachiocephalic trunk**: Is larger than the left subclavian, but is only short (~ 4cm).
Passes obliquely to the right and cranially across the ventral surface of the trachea.
Branches:

- **The left common carotid**
- **The right common carotid**
- **The right subclavian artery**

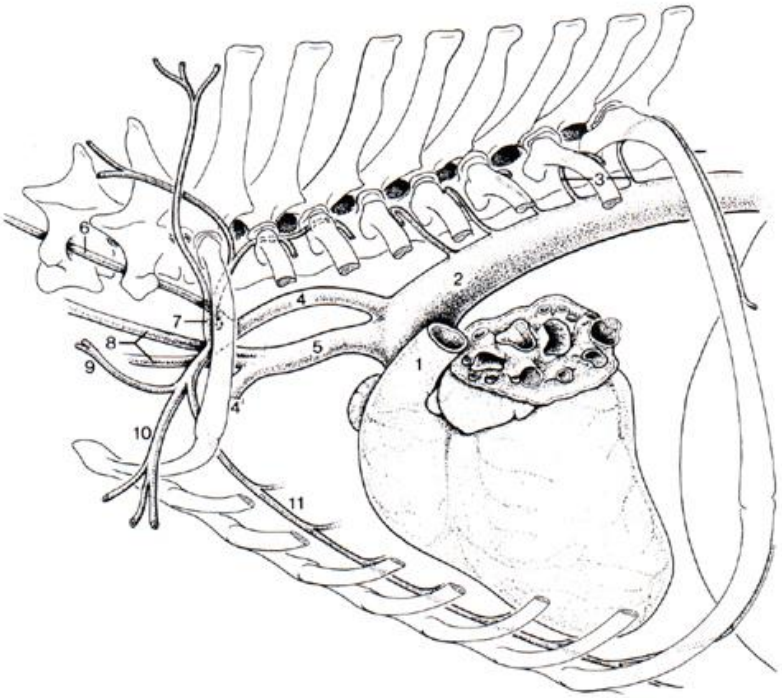
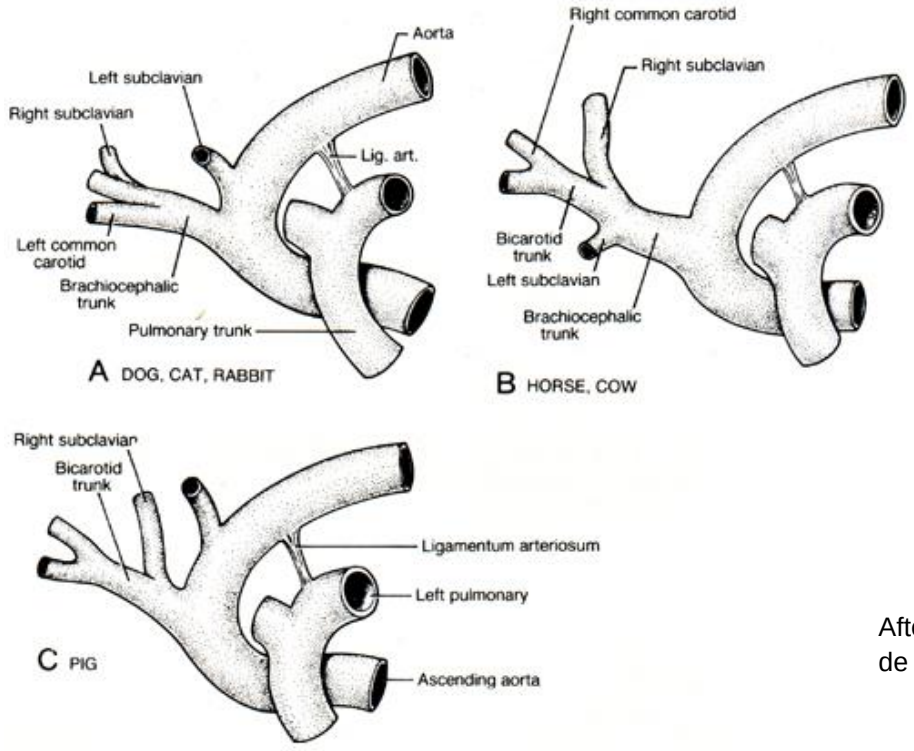


Figure 7–34. Branching of the aortic arch in the dog. (In this series of figures, not all arteries depicted are named.)

1, Pulmonary trunk; 2, aorta; 3, intercostal aa.; 4, left subclavian a.; 4′, right subclavian a.; 5, brachiocephalic trunk; 6, vertebral a.; 7, costocervical trunk; 8, left and right common carotid aa.; 9, superficial cervical a.; 10, axillary a.; 11, internal thoracic a.

Dyce et al 2002

Species variation:



After Noden and de Lahunta 1985

Figure 11.5. Species variation in the pattern of branching of major thoracic arteries.

The **left and right subclavian** arteries **each** give rise **4 main branches:**

1. The **vertebral artery -** supplies the cervical muscles, spinal cord, and brain (Circle of Willis).
2. The **costocervical artery** - extends dorsally as far as the vertebral end of the first rib and supplies the first to third intercostal spaces, the muscles at the base of the neck and the muscles of first three to four thoracic vertebrae.
3. The **internal thoracic artery** - supplies the thoracic wall.
4. The **superficial cervical artery** (or omocervical a.) - supplies the base of the neck and adjacent scapular region. The subclavian then leaves the thorax, winds around the cranial border of the first rib and continues, as the **axillary artery** as it passes through the axilla to continue down the limb**.**

Further Reading

Boyd, JS, Paterson, C, and May AH. Color atlas of clinical anatomy of the dog and cat, Second Edition. 2001.

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