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— STUDY NOTES

The Cardiac Cycle

The **cardiac cycle in animals** is the repeating sequence of one heartbeat: the ventricles **contract (systole)** to eject blood, then **relax (diastole)** to refill. It runs in four phases — **isovolumetric contraction → ejection → isovolumetric relaxation → filling** — and the whole thing is driven by **pressure gradients** that open and close the valves. Those valve closures are what you hear on auscultation: **S1 ("lub")** as the AV valves shut at the start of systole and **S2 ("dub")** as the aortic and pulmonic valves shut at its end. Master the pressures, volumes and sounds of one cycle and cardiac output, murmurs and heart failure all fall into place.

INSIDE THESE NOTES

LEVEL
Vets & veterinary students

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2026-07-03

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The Cardiac Cycle

STUDY NOTES · BASIC SCIENCES · PHYSIOLOGY · UPDATED 2026-07-03

CONTENTS

LEARNING OBJECTIVES

After working through these notes you will be able to:

- ✓ Define the cardiac cycle and distinguish ventricular systole from diastole.
- ✓ List the four phases of the cardiac cycle in order and state which valves are open or shut in each.
- ✓ Explain how pressure gradients open and close the AV and semilunar valves, and what the dicrotic notch is.
- ✓ Give the normal canine end-diastolic volume, end-systolic volume, stroke volume and ejection fraction, and the peak left- and right-ventricular pressures.
- ✓ State what produces the first and second heart sounds, and explain why S3 and S4 are normal in large animals but a gallop in dogs and cats.
- ✓ Write the cardiac-output equation and explain how preload (Frank-Starling), contractility and afterload change stroke volume.
- ✓ Interpret a pressure-volume loop and relate systolic and diastolic murmurs to valve stenosis and regurgitation.

TL;DR

The **cardiac cycle in animals** is the repeating sequence of one heartbeat: the ventricles **contract (systole)** to eject blood, then **relax (diastole)** to refill. It runs in four phases — **isovolumetric contraction** → **ejection** → **isovolumetric relaxation** → **filling** — and the whole thing is driven by **pressure gradients** that open and close the valves. Those valve closures are what you hear on auscultation: **S1 (“lub”)** as the AV valves shut at the start of systole and **S2 (“dub”)** as the aortic and pulmonic valves shut at its end. Master the pressures, volumes and sounds of one cycle and cardiac output, murmurs and heart failure all fall into place.

AT A GLANCE

WHAT THE CYCLE IS	One heartbeat = ventricular systole (contract, eject) + ventricular diastole (relax, fill)
THE FOUR PHASES	Isovolumetric contraction → ejection → isovolumetric relaxation → ventricular filling
WHAT MOVES THE VALVES	Pure pressure gradients — a valve opens/shuts the instant the pressure across it reverses
AV VALVES	Mitral (left) & tricuspid (right): shut at the start of systole (S1), open to fill
SEMILUNAR VALVES	Aortic & pulmonic: open to eject, shut at the end of systole (S2, the dicrotic notch)
VOLUMES (DOG)	EDV ~60 mL − ESV ~30 mL = stroke volume ~30 mL; ejection fraction ~50–65%
PRESSURES (DOG/LV)	Fills at <10 mmHg; ejects at ~120 mmHg (right side ~20 mmHg)
HEART SOUNDS	S1 & S2 always; S3/S4 normal in horses & cattle but a gallop (abnormal) in dogs & cats
CARDIAC OUTPUT	CO = heart rate × stroke volume; tuned by preload, contractility & afterload

01 Systole & diastole

- **The cardiac cycle = one heartbeat** = ventricular **systole** (contract & eject) + ventricular **diastole** (relax & fill). Unqualified, both terms mean the **ventricles**; the atria contract at the end of diastole.
- **One rule runs everything:** blood flows down pressure gradients, and each valve opens/shuts the instant the pressure across it reverses — no nerve tells the valves what to do.
- **Duration:** resting dog cycle ≈ 0.75 s; resting cow (~60 bpm) ≈ 1 s (systole 0.35 s, diastole 0.65 s). Diastole is the longer half — and shortens most as heart rate rises.

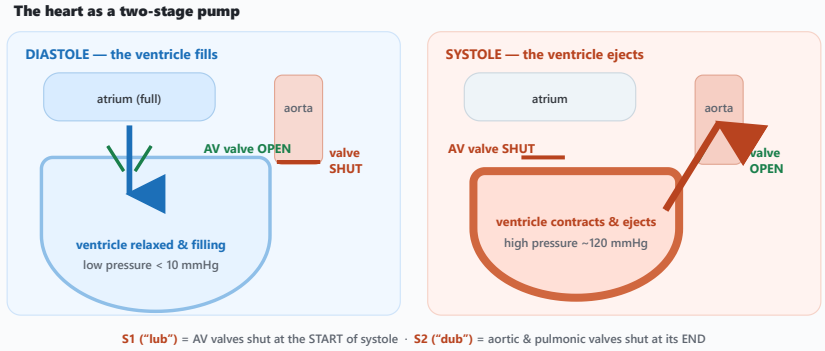

Fig 1 — Diastole: ventricle relaxed & full, AV valve open, aortic valve shut. Systole: ventricle contracts, AV valve shut (S1), aortic valve open, closing at end-systole (S2).

02 The four phases

- **1 Isovolumetric contraction** — all 4 valves shut; pressure rises, volume fixed.
- **2 Ejection** — semilunar valves open (LV > aortic); rapid then reduced ejection.
- **3 Isovolumetric relaxation** — all 4 valves shut again; pressure falls, volume fixed.
- **4 Ventricular filling** — AV valves open; three thirds: rapid filling → diastasis → atrial kick.
- **~80% of filling is passive** (atrial kick only ~20%) — so atrial fibrillation is survivable at rest but fails on exercise (short filling time).

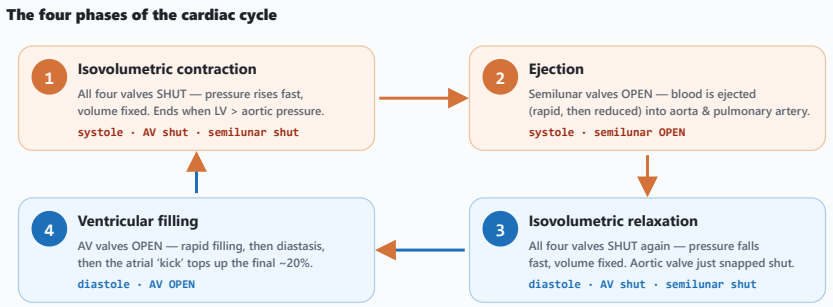

Fig 2 — IVC (all shut, P rising) → ejection (semilunar open) → IVR (all shut, P falling) → filling (AV open), then repeat.

03 The valves & pressures

- **AV valves** (mitral/bicuspid left, tricuspid right): shut when LV pressure > atrial (start systole), open when LV < atrial (start filling).
- **Semilunar valves** (aortic, pulmonic): open when LV > arterial (start ejection), shut when arterial > LV (end systole) → the **dicrotic notch**.
- **Pressures (dog):** LV fills <10 mmHg, peaks ~120 mmHg; RV peaks only ~20 mmHg. Aortic diastolic never drops below ~80 mmHg (perfuses coronaries).

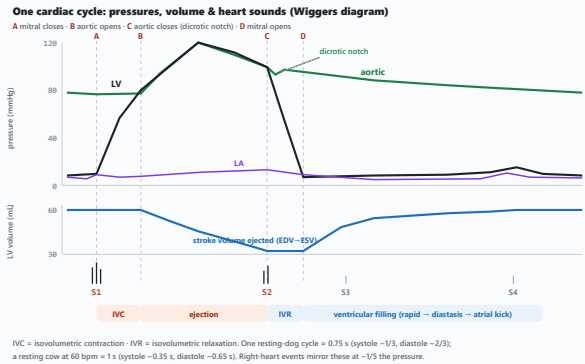

Fig 3 — Wiggers diagram: aortic, LV & LA pressures, LV volume and heart sounds aligned. A mitral closes, B aortic opens, C aortic closes (dicrotic notch), D mitral opens.

04 Volumes: EDV, ESV, SV & EF

- **Resting dog:** EDV ~60 mL − ESV ~30 mL = **stroke volume ~30 mL**. **Ejection fraction** = SV ÷ EDV ≈ 50% (rounded; normal 50–65%). LV preload ~5 mmHg, RV ~3 mmHg.
- **Exercise:** EDV steady/dips (~60→55) but ESV falls sharply (~30→15) → SV ~40 mL, EF ~50→73%, CO ~2.4→9.6 L/min (mostly better emptying, not more filling).
- **Compliance** = ΔV/ΔP; elastic limit ~90 mL (pericardial restraint). A **stiff ventricle** needs high filling pressure → backs up: stiff LV = pulmonary oedema, stiff RV = systemic oedema (diastolic heart failure).

05 The heart sounds

- **S1 ("lub")** = AV valves shut = START of systole (low-pitched, longer). **S2 ("dub")** = semilunar valves shut = END of systole (sharper, higher). Systole = the S1–S2 gap. A **split S2** = aortic & pulmonic close slightly apart.
- **S3** = rapid ventricular filling; **S4** = atrial contraction. **Species:** S3/S4 can be **normal in horses & cattle**, but in **dogs & cats** they are abnormal — a **gallop rhythm** (dilation/stiffening/failure).

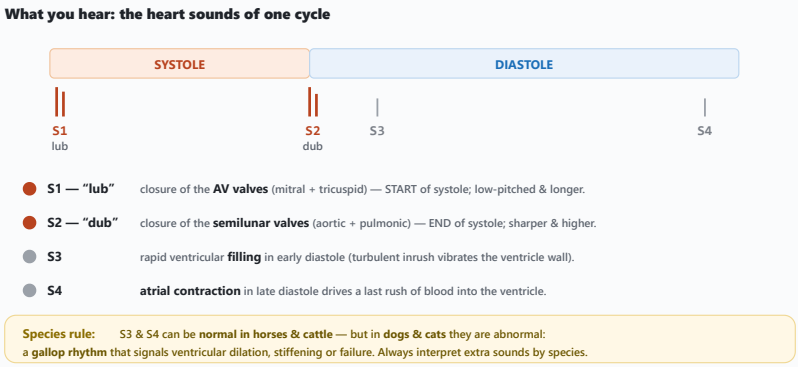

Fig 4 — S1 = AV closure (start systole), S2 = semilunar closure (end systole); S3/S4 normal in horses/cattle, a gallop in dogs/cats.

06 Murmurs

- Laminar flow is silent; a **murmur = turbulent flow** (stenosis, regurgitation, a shunt, or — with normal valves — **severe anaemia**: low viscosity + high output).
- **Systolic:** AV regurgitation (mitral/tricuspid), or semilunar stenosis (aortic/pulmonic). **Diastolic:** AV stenosis, or semilunar regurgitation. **Continuous 'machinery':** patent ductus arteriosus (young female dogs, left base).
- **Clinical:** mitral regurgitation in ~8% of dogs >5 yr — classic in the **Cavalier King Charles Spaniel**; aortic regurgitation common in horses, rare in dogs.

07 Cardiac output

- **CO = HR × SV.** Resting dog ~80 bpm × ~30 mL ≈ 2.4 L/min; 500 kg horse ~30 L/min at rest → up to ~250 L/min in exercise.
- **Stroke volume is tuned 3 ways: preload** (Frank-Starling: more in → more out, via EDV), **contractility** (sympathetic → lower ESV; anaesthetics/β-blockers depress it), **afterload** (arterial pressure opposing ejection; pressure work > volume work for hypertrophy).
- **Preload comes from venous return:** skeletal-muscle pump, respiratory pump, sympathetic venoconstriction, blood volume.
- **No free lunch on rate:** pacing/arrhythmia driving HR up (without sympathetic changes) shortens filling → EDV, SV, CO fall. In exercise sympathetic drive shortens systole + raises contractility, so 240 bpm still raises CO.

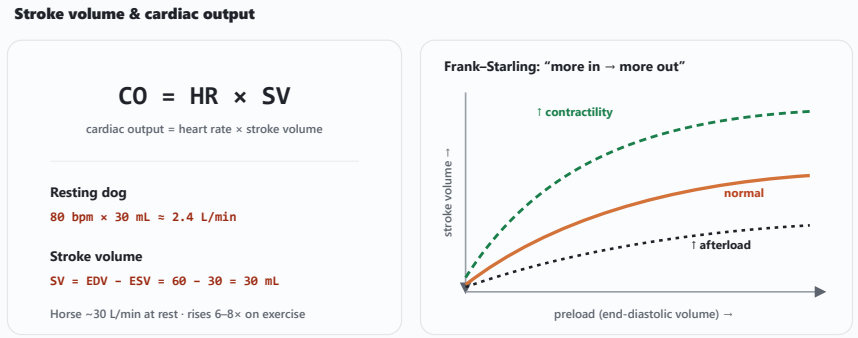

Fig 5 — CO = HR × SV (resting dog ~2.4 L/min). Frank-Starling: SV rises with preload; contractility lifts the curve, afterload lowers it.

08 The pressure–volume loop

- Travel it anticlockwise: **A** mitral closes → up (IVC) → **B** aortic opens → left (ejection) → **C** aortic closes → down (IVR) → **D** mitral opens → right (filling).
- **Loop width = stroke volume; loop area = stroke work.** Disease reshapes it (mitral leak widens it; a stiff ventricle lifts the filling limb; falling contractility shrinks it).

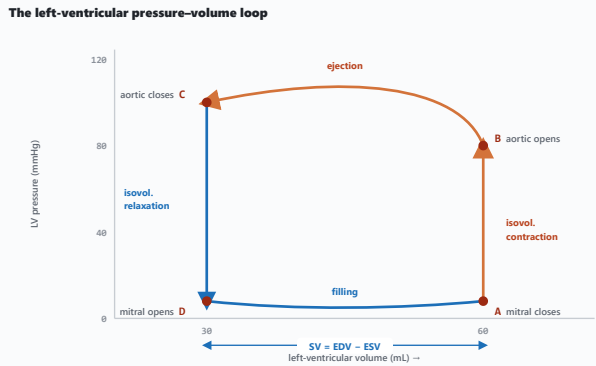

Fig 6 — The LV pressure-volume loop; each corner is a valve event (A–D) and the width is the stroke volume (EDV − ESV).

09 Species & clinical notes

- **Resting HR:** dog 70–140, cat 140–220, horse 28–44, cattle 60–80 bpm. Bigger/fitter = slower, longer cycle; diastole is sacrificed first as rate climbs.

- **Auscultation payoff:** S1 opens & S2 closes systole, so time any murmur/extra sound against the pulse — e.g. a left-apical systolic murmur in an old small-breed dog = mitral regurgitation. Read S3/S4 by species.

RED FLAG

A gallop (S3/S4) in a dog or cat, a loud or thrill-associated murmur, or any murmur with weakness, exercise intolerance or syncope — work up with echocardiography and refer.

> *Every valve waits for the pressure to flip — master one cardiac cycle and the sounds, the murmurs and cardiac output all fall into place.*
>
> — after Cunningham 6e Ch 21 & PDA 3e Ch 11.

KEY TERMS — QUICK GLOSSARY

Cardiac cycle	One complete heartbeat — ventricular systole (contraction/ejection) plus ventricular diastole (relaxation/filling).
Systole	The period of ventricular contraction; blood is ejected. Unqualified, 'systole' means ventricular systole.
Diastole	The period of ventricular relaxation and filling, between aortic-valve closure and the next mitral-valve closure.
Isovolumetric contraction	First phase of systole: all four valves shut, so ventricular pressure rises with no change in volume.
Ejection	Semilunar valves open (ventricular pressure > arterial); blood is ejected — rapid then reduced ejection.
Isovolumetric relaxation	First phase of diastole: all valves shut again, ventricular pressure falls with no change in volume.
Ventricular filling	Mitral/tricuspid valves open; rapid filling, then slow filling (diastasis), then the atrial 'kick'.
AV valves	Mitral (bicuspid, left) and tricuspid (right); shut at the start of systole (S1), open during filling.
Semilunar valves	Aortic and pulmonic; open during ejection, shut at the end of systole (S2).
Dicrotic notch (incisura)	The blip in the aortic pressure trace as the aortic valve snaps shut and blood recoils against it.
End-diastolic volume (EDV)	Ventricular blood volume at the end of filling — ~60 mL in a resting dog (preload).
End-systolic volume (ESV)	Ventricular blood volume left after ejection — ~30 mL in a resting dog (set by contractility & afterload).

Stroke volume (SV)	Blood ejected per beat = EDV − ESV (~30 mL in a resting dog).
Ejection fraction (EF)	SV ÷ EDV — the fraction of EDV ejected; ~50–65% is normal at rest in dogs.
Cardiac output (CO)	Blood pumped per ventricle per minute = heart rate × stroke volume (~2.4 L/min, resting dog).
Preload	The end-diastolic stretch on the ventricle; raising it raises EDV and, via Frank-Starling, stroke volume.
Frank-Starling law	'More in, more out' — a greater EDV stretches the fibres and produces a greater stroke volume.
Contractility	The intrinsic force of contraction (independent of preload); raised by sympathetic drive, lowering ESV.
Afterload	The arterial pressure the ventricle must overcome to eject; a sudden rise transiently lowers stroke volume.
Gallop (S3/S4)	A third or fourth heart sound audible in dogs/cats — abnormal there, though normal in horses and cattle.

QUICK REVISION — REMEMBER THESE

1. The **cardiac cycle in animals** is one heartbeat split into **systole** (the ventricles contract and eject) and **diastole** (the ventricles relax and fill) — and unqualified, "systole" and "diastole" always refer to the ventricles.
2. It runs as **four phases**: **isovolumetric contraction** (all valves shut, pressure rises, volume fixed) → **ejection** → **isovolumetric relaxation** (all valves shut, pressure falls) → **filling**.
3. Every valve movement is driven by a **pressure gradient**: the **AV valves** (mitral, tricuspid) shut when ventricular pressure rises above atrial; the **semilunar valves** (aortic, pulmonic) open when ventricular pressure rises above arterial.
4. The two heart sounds are valve closures: **S1 ("lub")** is AV-valve closure at the *start* of systole, and **S2 ("dub")** is semilunar-valve closure at its *end* — so ventricular systole is the interval between S1 and S2.
5. In a resting dog each ventricle holds ~**60 mL at end-diastole (EDV)**, ejects ~**30 mL (stroke volume)** and keeps ~**30 mL (ESV)** — an **ejection fraction of ~50–65%**; the left ventricle peaks at ~120 mmHg, the right at only ~20.
6. **Cardiac output = heart rate × stroke volume** (a resting dog: ~80 bpm × ~30 mL ≈ 2.4 L/min), and it is tuned three ways — **preload** (Frank–Starling), **contractility** and **afterload**.
7. Most ventricular filling (**~80%**) happens passively *before* the atria contract, so the atrial "kick" adds only the final ~20% — which is why an animal in **atrial fibrillation** can still pump a near-normal stroke volume at rest.

8 **Species point:** the third and fourth heart sounds (**S3, S4**) can be entirely normal in horses and cattle, but in a dog or cat the same sounds are abnormal — a **gallop rhythm** that flags heart disease.

MEMORY AIDS

Systole = Squeeze — **S**ystole = the ventricle **S**queezes (contracts, ejects). Diastole = it dilates and fills. Unqualified = the ventricles.

"Every valve waits for the pressure to flip" — A valve opens or shuts the instant the pressure across it reverses — nothing else moves them. No muscles, just gradients.

LUB shuts AV, DUB shuts semilunar — **S1 (lub)** = **A**V valves shut = **start** of systole. **S2 (dub)** = **semilunar** valves shut = **end** of systole. Systole is the S1–S2 gap.

SV = EDV − ESV — **Stroke volume** = what went in (EDV ~60) minus what stayed (ESV ~30) = ~30 mL in a dog. **EF** = SV ÷ EDV (~50%).

CO = HR × SV — **C**ardiac **O**utput = **H**eart **R**ate × **S**troke **V**olume. Tune SV three ways: **preload, contractility, afterload**.

80/90 before the kick — **80–90%** of filling is passive, **before** the atrial kick — so atrial fibrillation is survivable at rest but fails on exercise.

S3/S4: big animals OK, small animals gallop — **S3 & S4** are normal in **horses/cattle** but a **gallop** (disease) in **dogs/cats**.

TEST YOURSELF — ACTIVE RECALL

Cover the answers and try to retrieve each one from memory first — self-testing beats re-reading.

1. **Define the cardiac cycle and name its two halves.**
2. **List the four phases of the cardiac cycle in order, with the valve states of each.**
3. **What opens and closes the heart valves?**
4. **Give the normal resting canine EDV, ESV, stroke volume and ejection fraction.**
5. **What causes the first and second heart sounds, and what is the dicrotic notch?**
6. **Write the cardiac-output equation and name the three determinants of stroke volume.**
7. **Why can an animal in atrial fibrillation still pump a near-normal stroke volume at rest?**
8. **Why are S3 and S4 normal in a horse but abnormal in a dog?**

ANSWERS

1. The cardiac cycle is one complete heartbeat. Its two halves are ventricular systole (the ventricles contract and eject blood) and ventricular diastole (the ventricles relax and refill). Unqualified, systole and diastole refer to the ventricles.
2. 1) Isovolumetric contraction — all four valves shut. 2) Ejection — semilunar valves open, AV valves shut. 3) Isovolumetric relaxation — all four valves shut. 4) Ventricular filling — AV valves open, semilunar valves shut.

3. Pure pressure gradients. AV valves shut when ventricular pressure rises above atrial pressure (start of systole) and open when it falls below atrial pressure (start of filling). Semilunar valves open when ventricular pressure exceeds arterial pressure (start of ejection) and shut when arterial pressure exceeds ventricular pressure at the end of systole.
4. EDV ~60 mL, ESV ~30 mL, so stroke volume ~30 mL, giving an ejection fraction of ~50% (50–65% is the normal resting range). Peak left-ventricular pressure ~120 mmHg; peak right-ventricular pressure ~20 mmHg.
5. S1 ('lub') is closure of the AV valves at the start of systole (low-pitched, longer); S2 ('dub') is closure of the semilunar valves at the end of systole (sharper, higher-pitched). The dicrotic notch is the small rise in aortic pressure as the aortic valve snaps shut and the recoiling blood is arrested.
6. Cardiac output = heart rate × stroke volume (a resting dog: ~80 bpm × ~30 mL ≈ 2.4 L/min). Stroke volume is set by preload (Frank-Starling / EDV), contractility (which lowers ESV) and afterload (arterial pressure, which opposes ejection).
7. Because roughly 80% of ventricular filling occurs passively before the atria contract; the atrial 'kick' adds only the final ~20%. At rest the lost atrial contribution barely matters, though during exercise (short filling time) or with mitral stenosis it becomes important, so these animals show exercise intolerance.
8. In large animals (horses, cattle) the third sound (rapid ventricular filling) and fourth sound (atrial contraction) are often audible in normal hearts. In small animals the same sounds are pathological — a 'gallop rhythm' that signals ventricular dilation, stiffening or failure.

WHEN TO REFER OR ESCALATE

- A new **systolic murmur** at the left apex in an older small-breed dog (especially a Cavalier King Charles Spaniel) — degenerative **mitral regurgitation**; work up with echocardiography.
- A **gallop rhythm (S3 or S4)** in a dog or cat — abnormal in small animals; investigate for dilated or hypertrophic cardiomyopathy or failure.
- A **continuous 'machinery' murmur** over the left heart base in a young dog — likely a **patent ductus arteriosus**; refer for closure, ideally young.
- A loud (grade IV–VI) or **thrill**-associated murmur, or any murmur with weakness, exercise intolerance or fainting — characterise fully and refer.
- A resting horse with a **dropped beat** that disappears on exercise is usually normal (physiological second-degree AV block) — but a fast, irregular rhythm needs an ECG for atrial fibrillation.

SOURCES

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2. Sjaastad ØV, Sand O, Hove K. The Pumping Function of the Heart. In: Physiology of Domestic Animals. 3rd ed. Oslo: Scandinavian Veterinary Press; 2016. Chapter 11 (pp 451–470): the cardiac cycle phases and the thirds of ventricular filling (atrial contraction ~20–30%); AV and semilunar valve events and the dicrotic notch as arrested backflow; the heart sounds S1 ('lub') and S2 ('dub'); cardiac output = HR × SV with species values (20 kg dog ~2 L/min, 500 kg horse ~30 L/min, rising to ~250 L/min in exercise); the Frank-Starling mechanism and venous-return determinants; resting cardiac-cycle duration in the cow (~1 s; systole 0.35 s, diastole 0.65 s) and the resting heart-rate table (horse 32–44, cattle 60–70, dog 70–120 bpm); murmurs from stenotic/leaky valves and the mitral-valve susceptibility of the Cavalier King Charles Spaniel.
3. Klein BG (ed.). Cunningham's Textbook of Veterinary Physiology, 6th ed. — Chapters 19–20 for the conduction system and electrocardiogram that time the mechanical cycle described here (see our companion articles on the cardiac action potential and ECG interpretation).

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