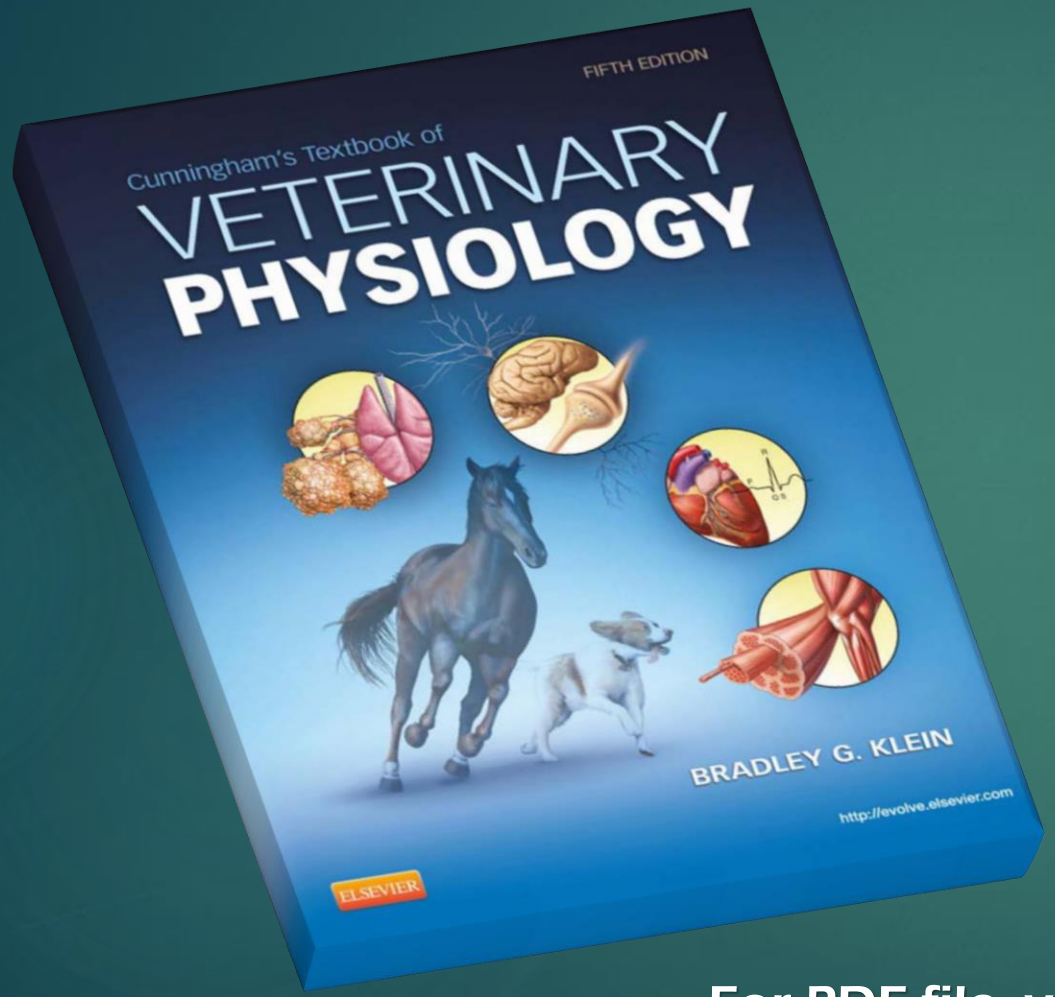
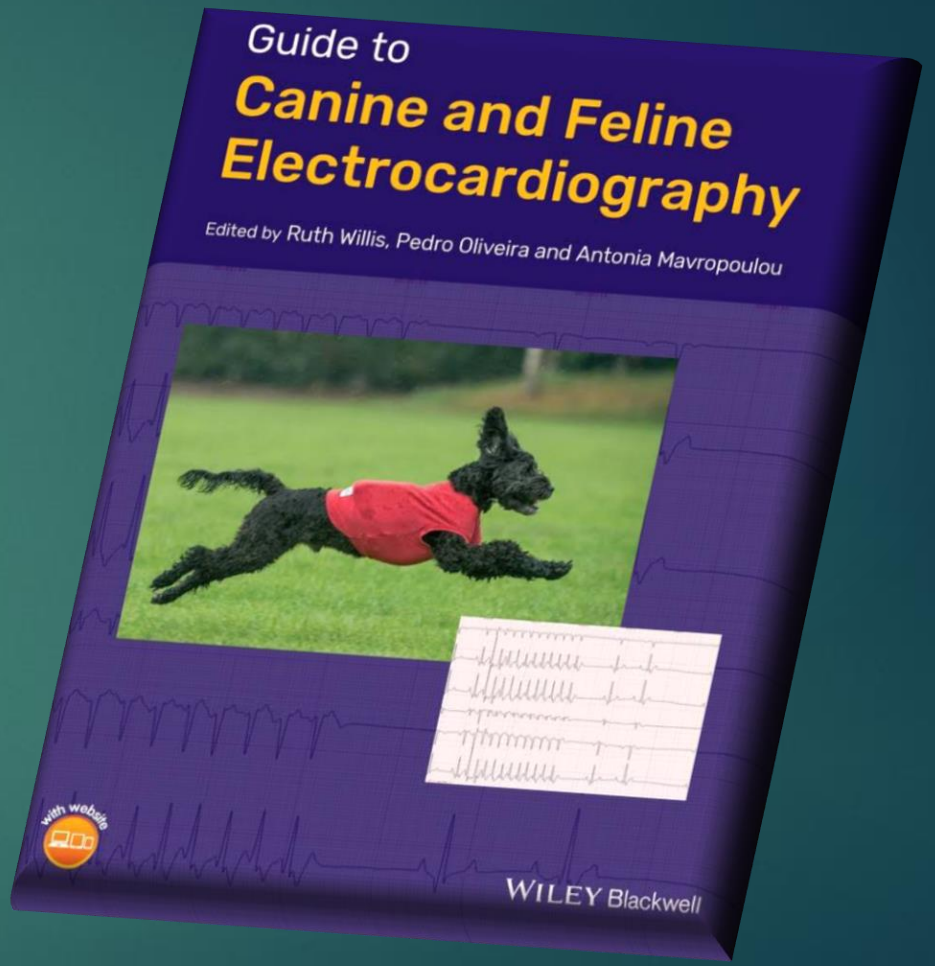
Electrocardiography in Veterinary Medicine

A. K.Goudarzi, D.V.M. Ph.D.
Department of Basic Sciences
I. A. University

References





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Introduction

- **Electrocardiography** - graphic recording of the electrical activity (potentials) produced by the conduction system and the myocardium of the heart during its depolariztion / repolarization cycle.
- During the late 1800's and early 1900's, Dutch physiologist **Willem Einthoven** developed the early electrocardiogram. He won the Nobel prize for its invention in 1924.
- **Hubert Mann** first uses the electrocardiogram to describe electrocardiographic changes associated with a heart attack in 1920.

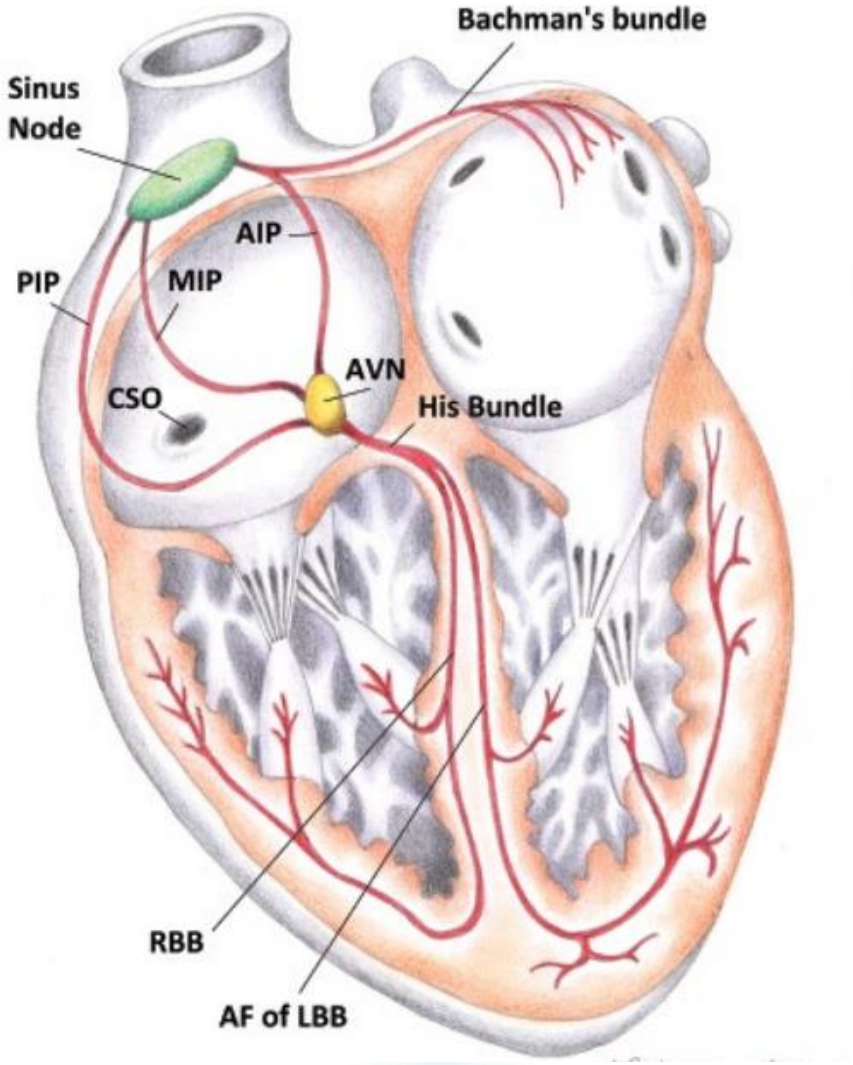
Introduction

- The science of electrocardiography is not exact. The sensitivity and specificity of the tool in relation to various diagnoses are relatively low.

- Electrocardiograms must be viewed in the context of demographics, health histories, and other clinical test correlates. They are especially useful when compared across time to see how the electrical activity of the heart has changed (perhaps as the result of some pathology).

Introduction

- The heart possesses a specialized conduction system that is responsible for generating and transmitting electrical stimuli to the whole heart in a specific and ordered fashion
- It is composed of the sinoatrial node (SA), internodal and inter-atrial pathways, atrioventricular junction, bundle branches and Purkinje fibers.



Section I

Cardiac Electrophysiology

Cardiac Electrophysiology

Cardiac cells may be broadly divided into:

- pacemaker cells (SA node, AVN, His-purkinje cells)
  - responsible for spontaneous generation of electrical impulses
- specialized conduction cells (Autorhythmic cells)
  - responsible for rapid (e.g. Purkinje cells) or slow (e.g. AVN) propagation of the electrical impulse
- the working myocardium (contractile cells)
  - responsible for muscle contraction

Cardiac Electrophysiology

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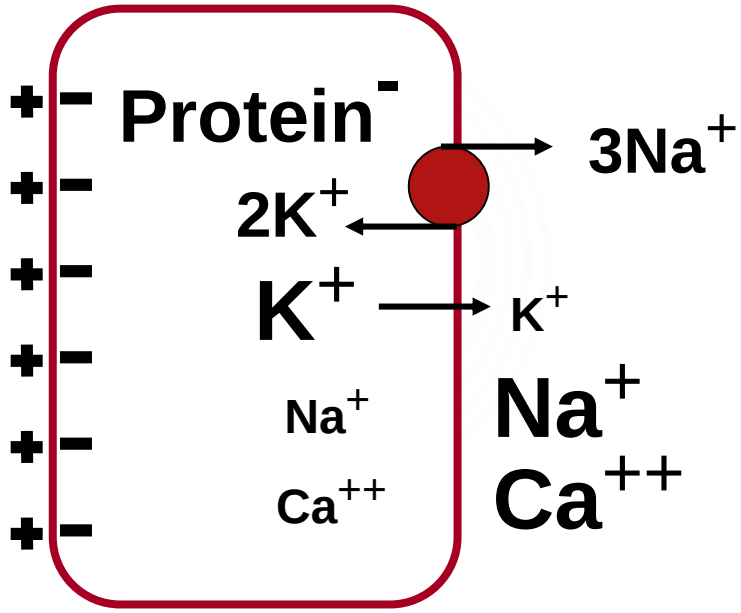
- The ability of cells to generate and propagate electrical impulses is linked to the presence and movement of particles (ions or electrolytes) with positive or negative charges between both sides of the cell membrane.
  - Mammalian cells are rich in potassium (K+ = 150 mmol/L) and magnesium (Mg2+ = 12 mmol/L) and are bathed by fluid in the extracellular space that is rich in sodium (Na+ = 140 mmol/L), calcium (Ca2+ = 1 mmol/L), chloride (Cl = 110 mmol/L) and bicarbonate (HCO3 − = 30 mmol/L)



Resting Membrane Potential

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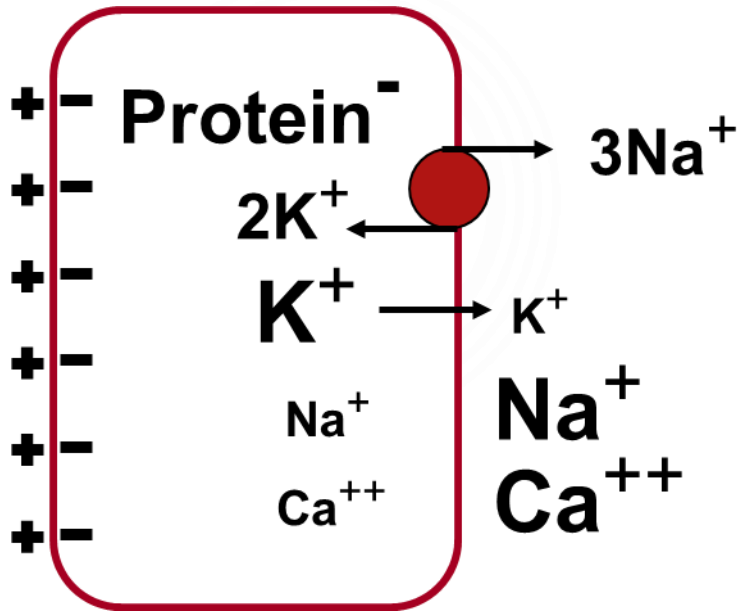
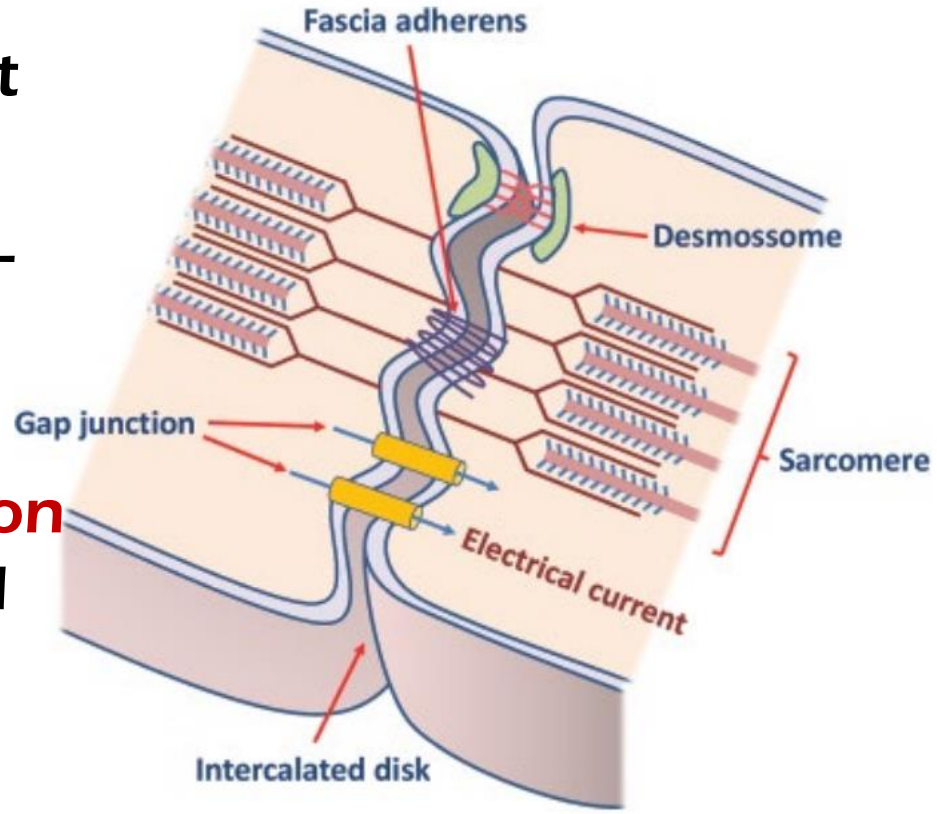
- In the resting state, the inside of the cell is negatively charged, in contrast to the outside in which positive charges prevail. This is mainly due to different concentrations of Na+ and K+ molecules on both sides of the cell membrane.
- The cell interior is rich in K+ and the extracellular space is rich in Na+. Numerous sodium–potassium pumps in the cell membrane constantly remove sodium from the cell (three Na+ molecules) in exchange for potassium (two K+ molecules), and this accounts for the accumulation of K+ in the cell and of Na+ in the extracellular space.
- The RMP of the various cardiac cells varies from −50 to −95 mV



Cardiac Cell Structure and Function

- The cardiac muscle is organised as a syncytium of cells that are tightly interlinked by the presence of special junctions between adjacent cell called intercalated disks.
- These are composed of specialised structures – desmosomes and fascia adherens – that form tight junctions
- Another structure is called nexus or gap junction which allows the passage of ions from one cell to the next through aqueous pores, making it possible for the depolarisation wave to be transmitted from cell to cell.



Cell Depolarisation and the Action Potential

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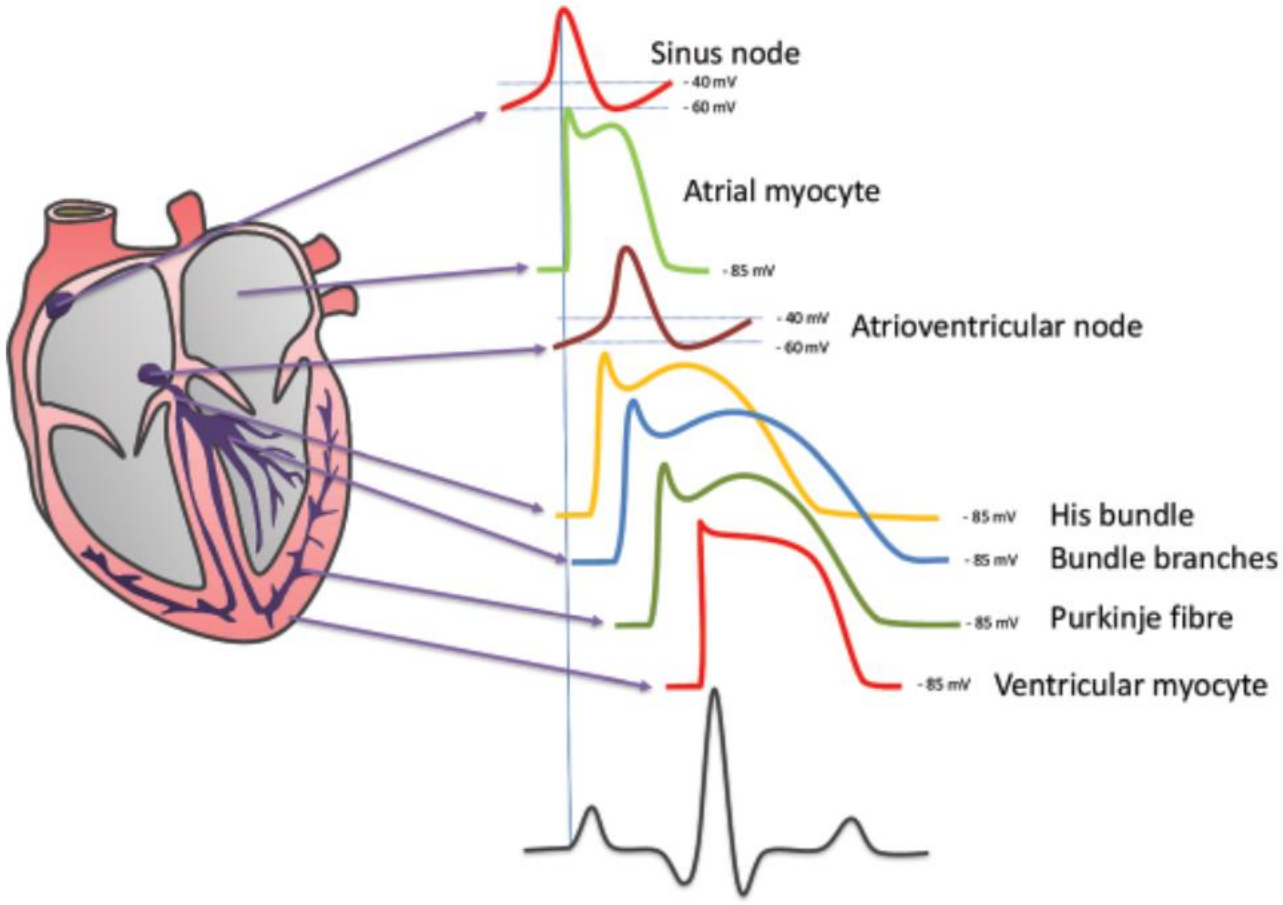
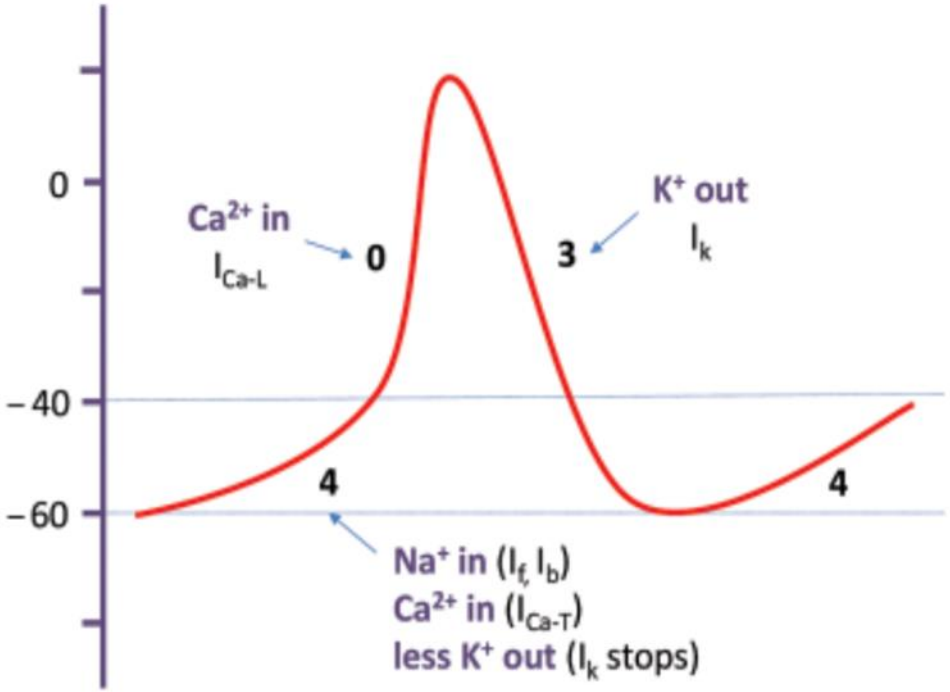
- Normally, the pacemaker cells in the sinoatrial node are responsible for initiating the depolarisation wave, which is then transmitted to all the cardiac myocytes.
- There are substantial differences between the depolarisation of conduction system cells (e.g. pacemaker cells, compact node cells and Purkinje cells) and working myocardial cells (e.g. atrial and ventricular).



Pacemaker Action Potential

- During the resting state (stage 4), there is a spontaneous increase in membrane potential due to a combination of inward flow of Na+(I_f) and Ca2+($I_{Ca\text{-}T}$), and a reduction in outward flow of K+(I_k).
- When the depolarisation threshold is reached at approximately −40 mV, L-type Ca2+ channels open, allowing Ca2+ to enter the cell causing cell depolarisation (stage 0) until they become inactivated less than 1 ms later. Cell repolarisation then follows via outward flow of K+(I_k).



Ventricular Myocyte Action Potential

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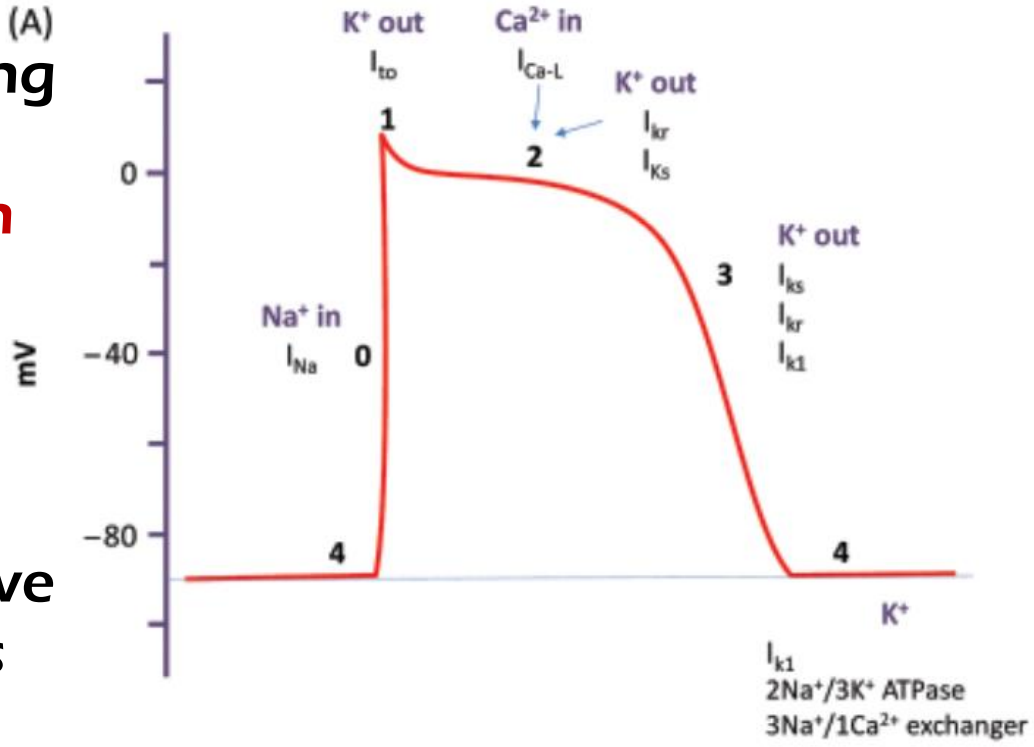
- **Stage 0** (rapid depolarisation due to inward flow of Na+)
  - An action potential triggered in a neighbouring cell causes a slight increase in potential to around −70 to −60 mV, which is the **activation threshold for sodium channels**

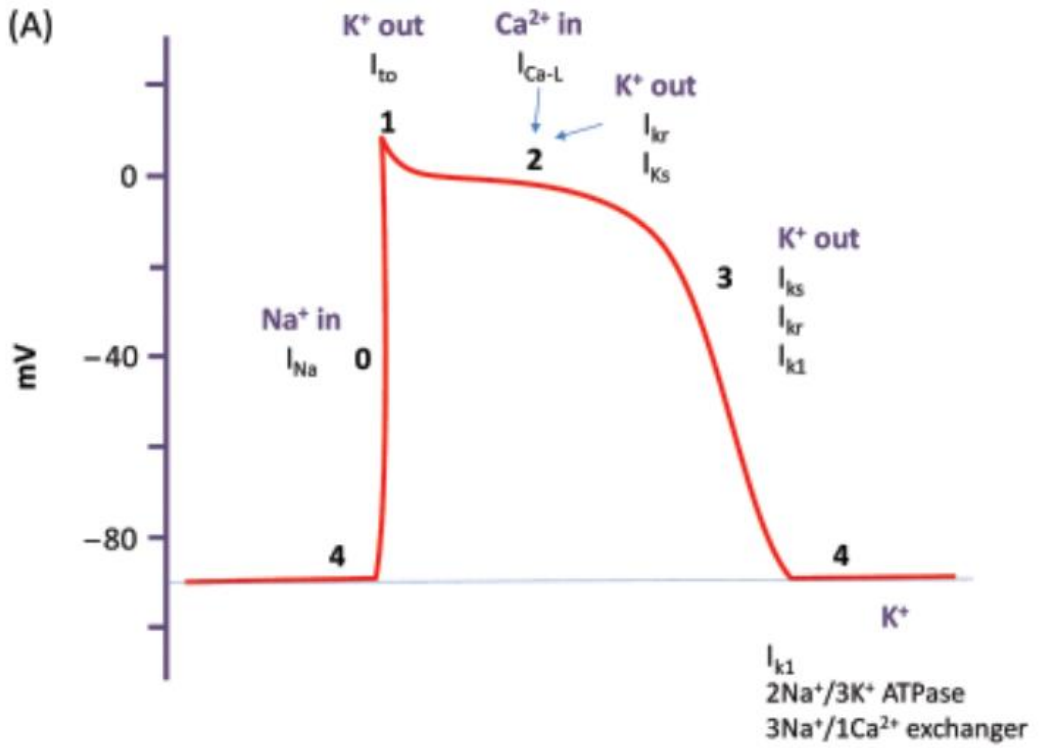


- **Stage 1** (rapid repolarisation)
  - With the increase in membrane potential above 0 mV, another type of voltage-gated channels (I_{to}) become activated, allowing the **exit of K+ from the cell**

Ventricular Myocyte Action Potential

I

- **Stage 2** (plateau phase)
  - During this stage, there is a combination of several ion currents involving a balance between entry of Ca2+ in the cell ($I_{Ca\text{-}L}$) and exit of K+ (I_K and I_{to})
  - During this period, the inward Ca2+ flow will trigger release of Ca2+ from the sarcoplasmic reticulum, causing muscle contraction in working myocardial cells



Ventricular Myocyte Action Potential

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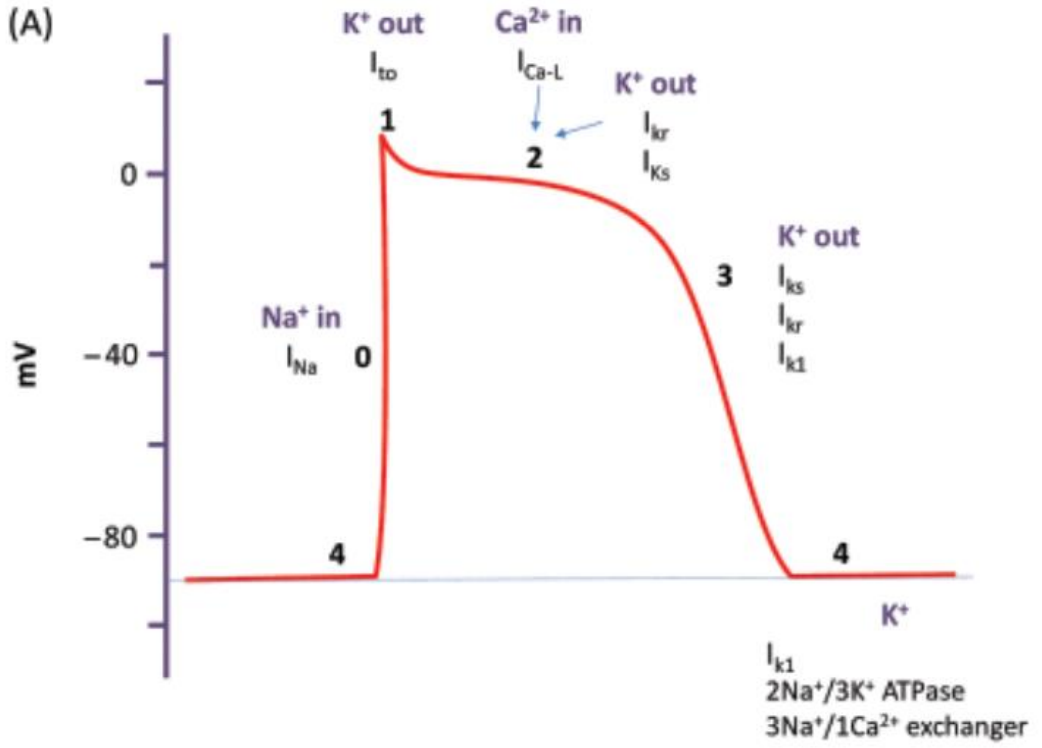
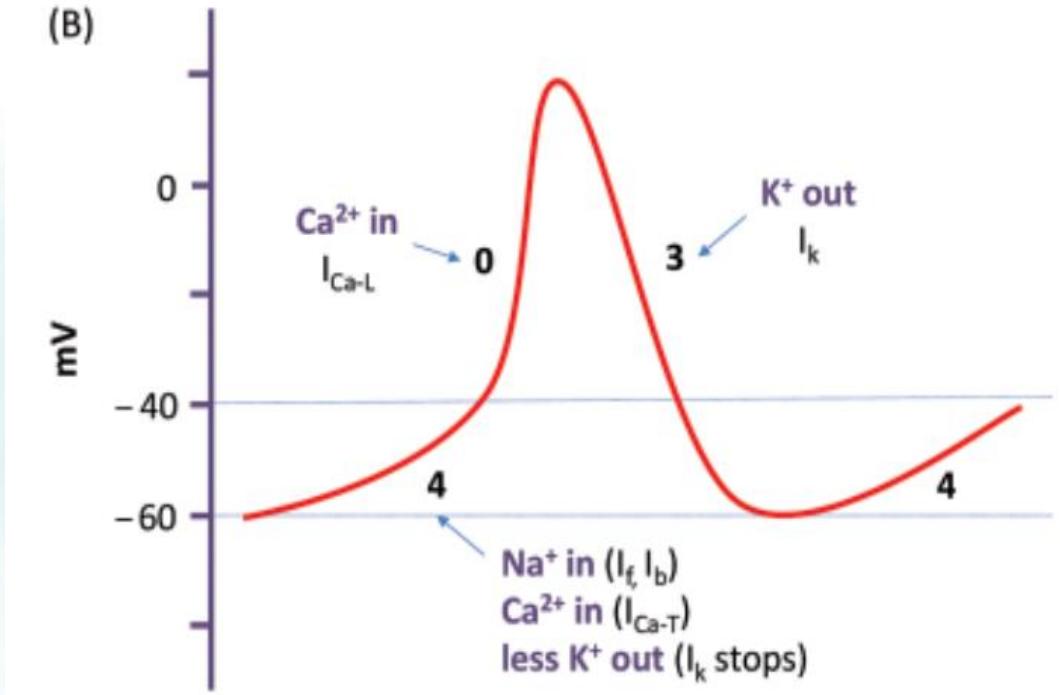
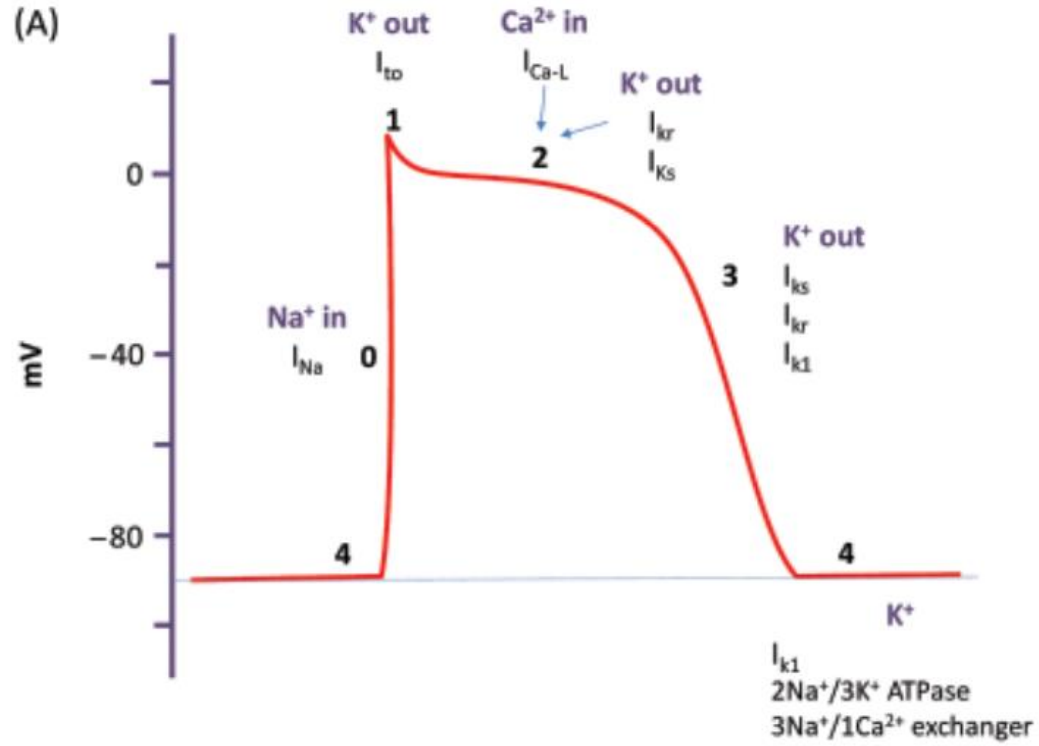
- **Stage 3** (repolarisation)
- As the L-type calcium channels become inactivated and the $I_{ca\text{-}L}$ current stops, the **outward currents of K+** continue until the RMP is restored once again.



- **Stage 4** (resting state)
  - During this stage, the changes that occurred during depolarisation are rectified. The **3Na+/2K+ ATPase pumps** and the **3Na+/1Ca2+ exchanger** work to remove the excess Na+ and Ca2+ from the cell and restore the K+ levels.

Pacemaker vs. Ventricular Myocyte APs



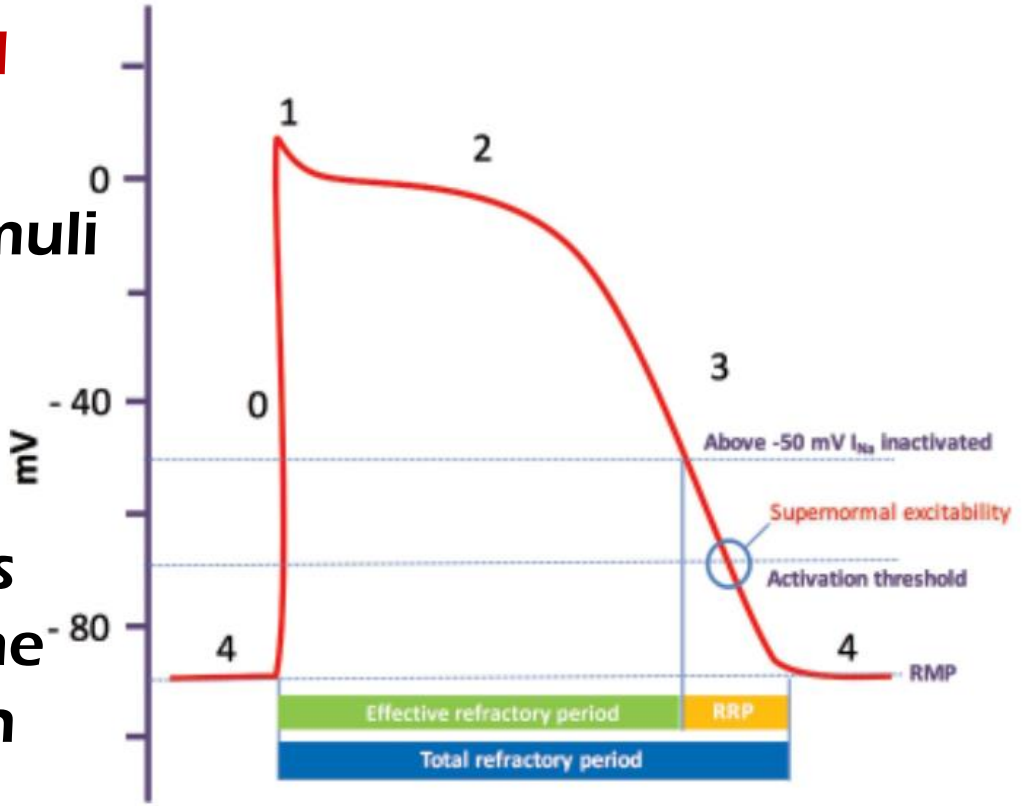


Pacemaker cell

Ventricular Myocyte

Cell Excitability and Refractoriness

- Once depolarisation is triggered, the cell is unable to generate another action potential until repolarisation occurs (from stage 0 until the end of stage 3).
- The cell becomes refractory to additional stimuli during this period because the fast sodium channels become inactivated at membrane potentials above −50 mV.
- Until the membrane potential falls below this threshold during stage 3 of repolarisation, the cell is incapable of generating another action potential regardless of the intensity of the triggering stimulus. This is the effective refractory period (ERP)



Cell Excitability and Refractoriness

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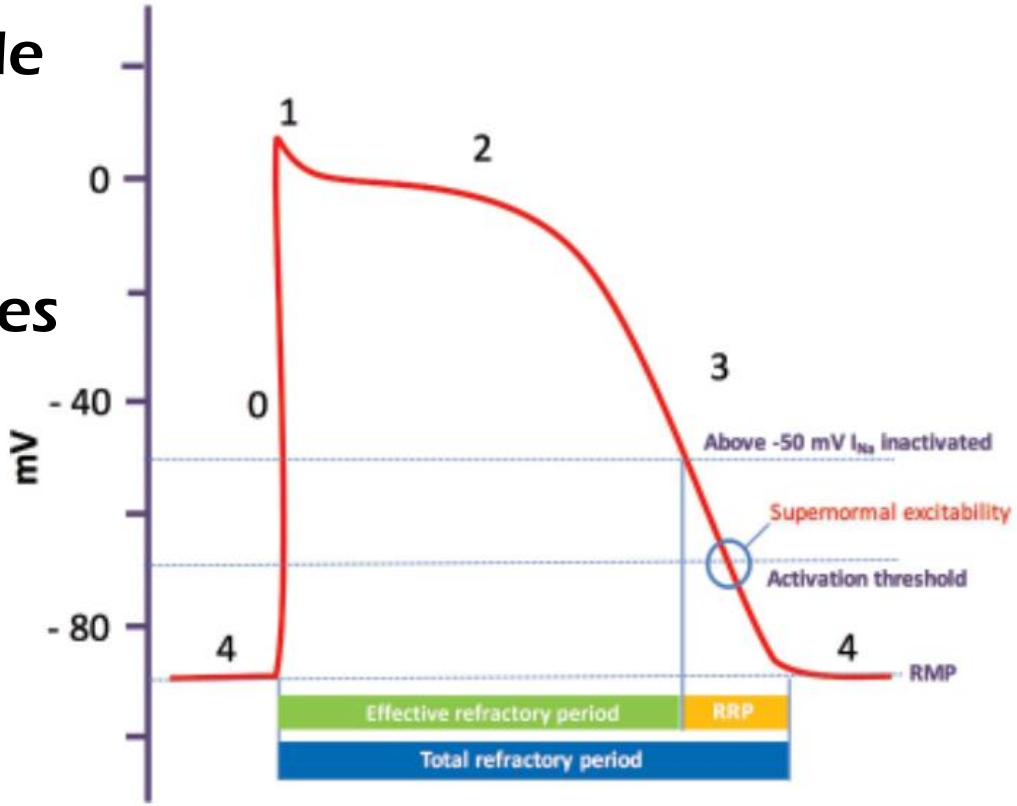
- Whilst the membrane potential is between −50 mV and the RMP (-85 to -90 mV), it may be possible for a stimulus of sufficient magnitude to trigger an early depolarisation.
- The resulting action potential will have a slower stage 0 and will achieve lower voltages which result in a slower conduction velocity, as a proportion of fast sodium channels are still inactive at this stage. This is the relative refractory period (RRP).



Cell Excitability and Refractoriness

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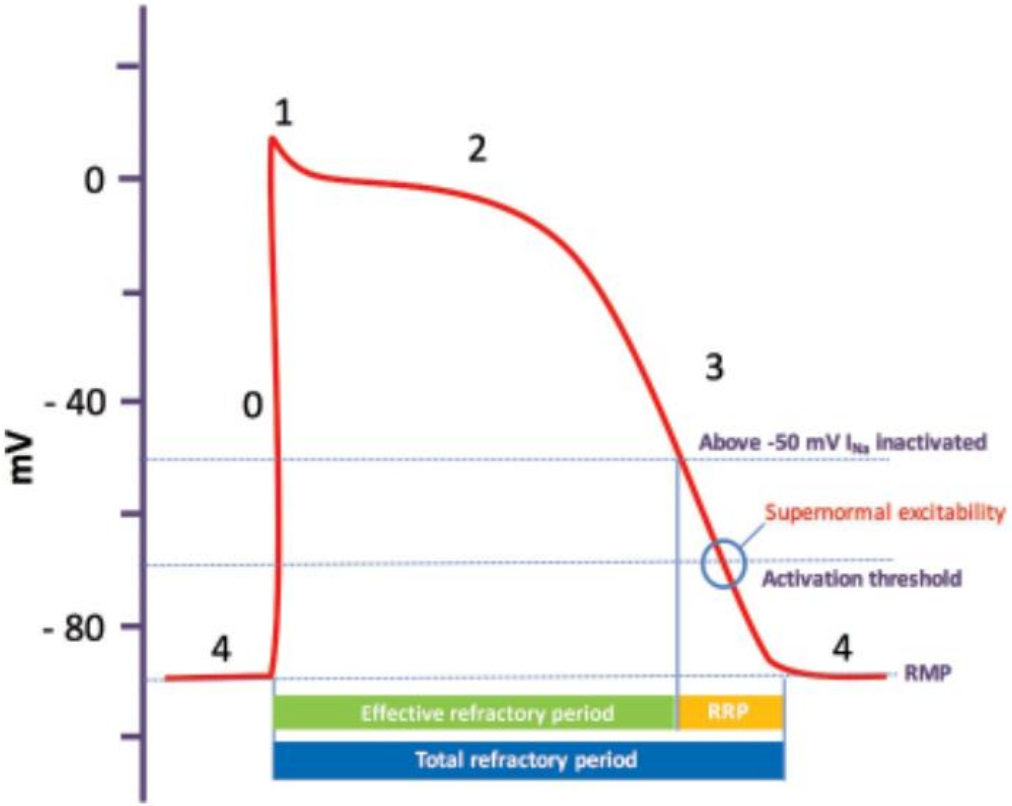
- By the end of the RRP, there is a period called the vulnerable period in which a stimulus of sufficient intensity may cause a repetitive response
- A relevant example would be the triggering of ventricular fibrillation when a premature beat (an ectopic or paced beat) happens to occur during the vulnerable period which on the electrocardiogram corresponds to the peak of the T wave.
- The vulnerable period for the atrial myocardium occurs during the descending R wave or during the S wave of the electrocardiogram.



Autonomic Control of the Pacemaker Cells

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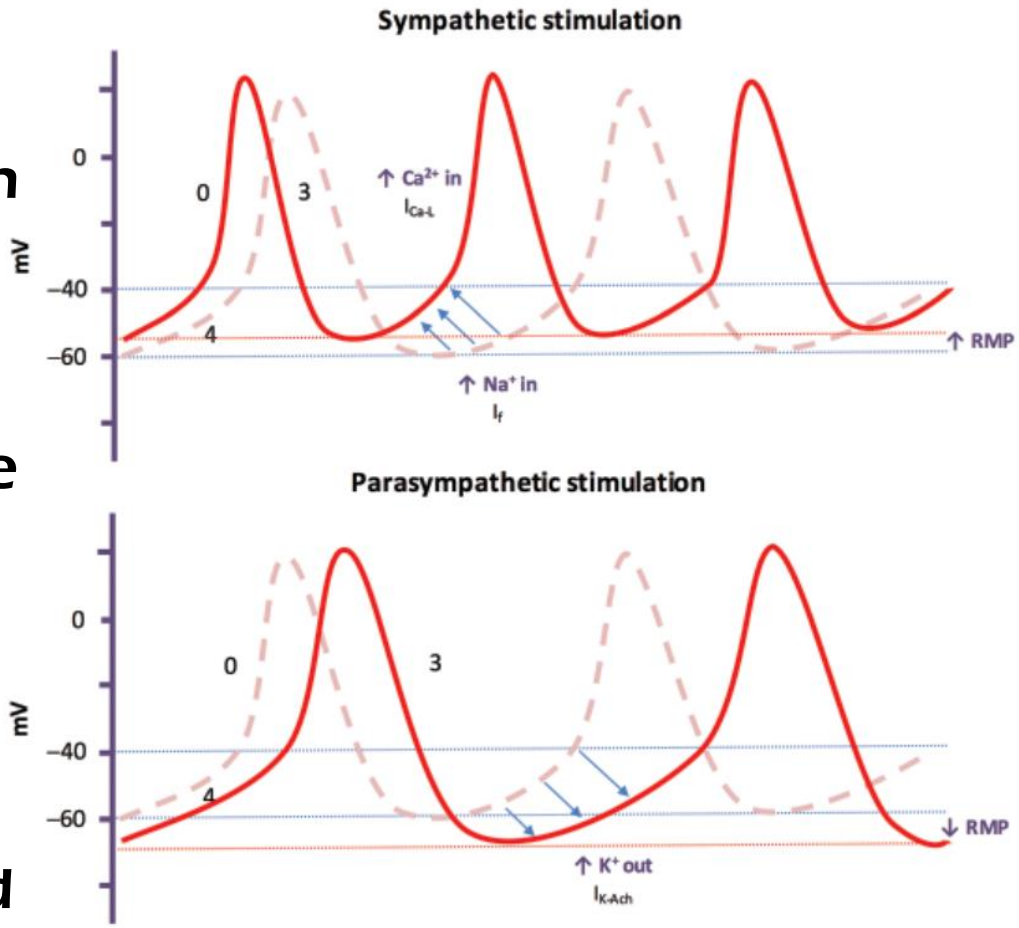
- **Sympathetic stimulation** results in an increase in **inward sodium** (I_f) and calcium ($I_{Ca\text{-}L}$) currents via increased levels of cAMP inside the cell.
  - The end result is a faster rate of depolarisation during stage 4, ultimately resulting in a faster heart rate
- **Parasympathetic stimulation** causes an increase in **outward K+** currents during stage 4 via activation of acetylcholine–ligand potassium channels (I_{KACh}).
  - This reduction in intracellular K+ leads to a lower resting membrane potential (hyperpolarisation), making it more difficult for the activation threshold to be reached and effectively lowering the heart rate



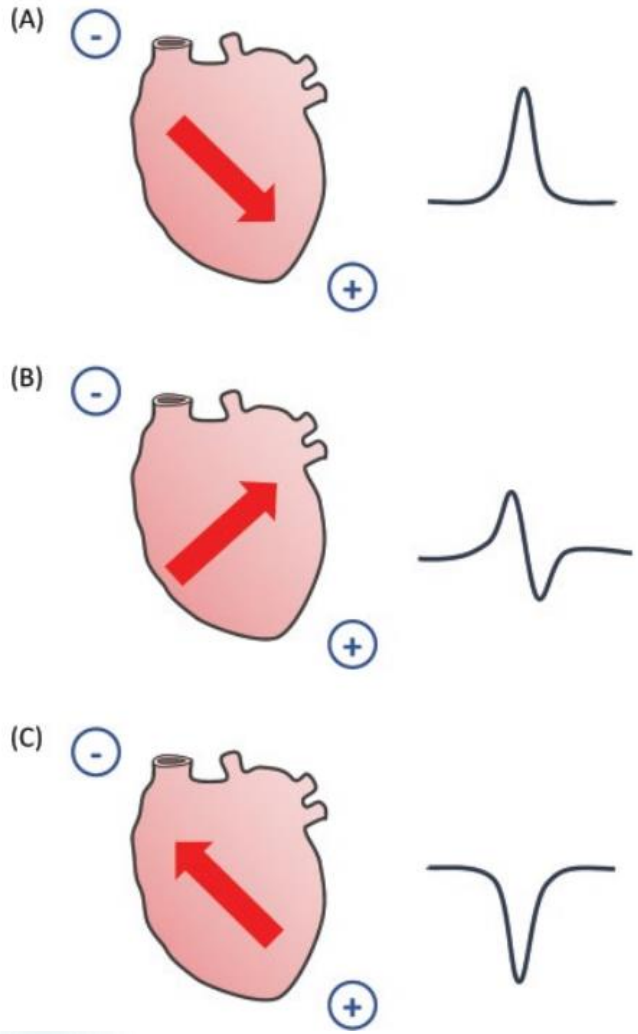
Section II

Cardiac Vectors and the Genesis of the ECG

The Electrocardiograph

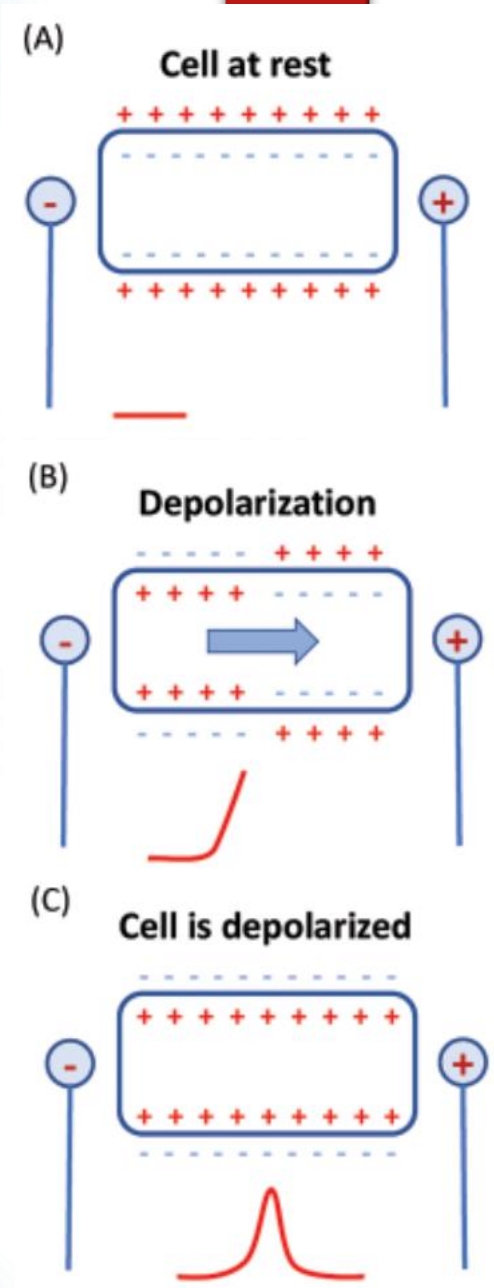
II

- The electrocardiograph is a galvanometer
  - It detects the presence, direction and strength of electrical currents
  - It uses two electrodes: positive pole (exploring electrode) negative pole (indifferent or reference electrode)
  - If the electrical current moves towards the (+) pole, a positive deflection is recorded (A).
  - If the exploring electrode is perpendicular to the direction of the electrical current, a positive deflection followed by a negative deflection is seen as the current moves towards the electrode initially and then away from it (B).
  - If the electrical current moves away from the (+) pole , a negative deflection is recorded (C).



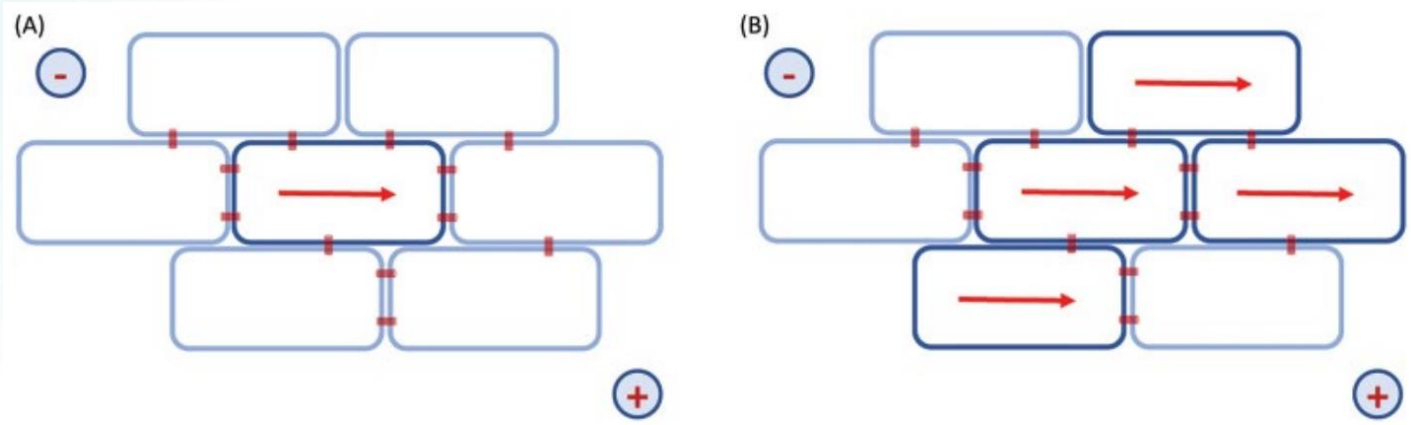
The Electric Dipole

- In the resting state, there is a prevalence of negative charges inside the cell in contrast to the outside compartment
- As depolarisation starts, an area of the cell will start to fill up with positive charges (positive pole), whilst in the other end negative charges still prevail (negative pole)
- This creates an electrical dipole with a potential difference between both extremities of the cell.
- This potential difference (voltage) could be recorded and displayed graphically over time (ECG).
- Before depolarisation, a flat line (baseline) is seen



Cardiac Vectors

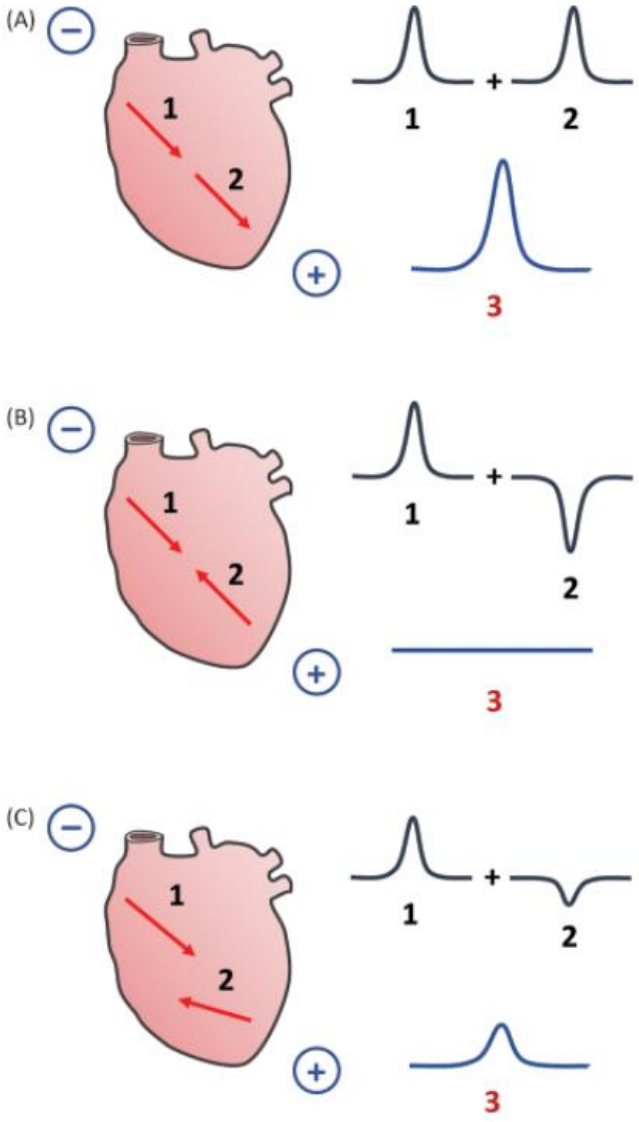
- A vector is a diagrammatic way to represent the direction and strength of an electrical impulse.
- In the example given in 'The electric dipole' section, the electrical impulse caused by depolarisation of a single cardiac cell can be represented as a small vector pointing in the direction of depolarization.
- Now imagine that the cells to the left, to the right and in front of that cell are depolarised. This creates three new vectors with different directions
- These three individual vectors can be added or subtracted.



Cardiac Vectors

II

- Vectors going in the same direction add up, whilst vectors travelling in opposite directions cancel each other out.
  - (A) Two vectors travelling in the same direction add up (1+2), resulting in a larger electrocardiographic deflection (3) than they would individually
  - (B) Two vectors of the same amplitude travelling in the exact opposite direction cancel each other out and do not cause a deflection on the electrocardiogram
  - (C) Two vectors travelling at an angle add or subtract energy



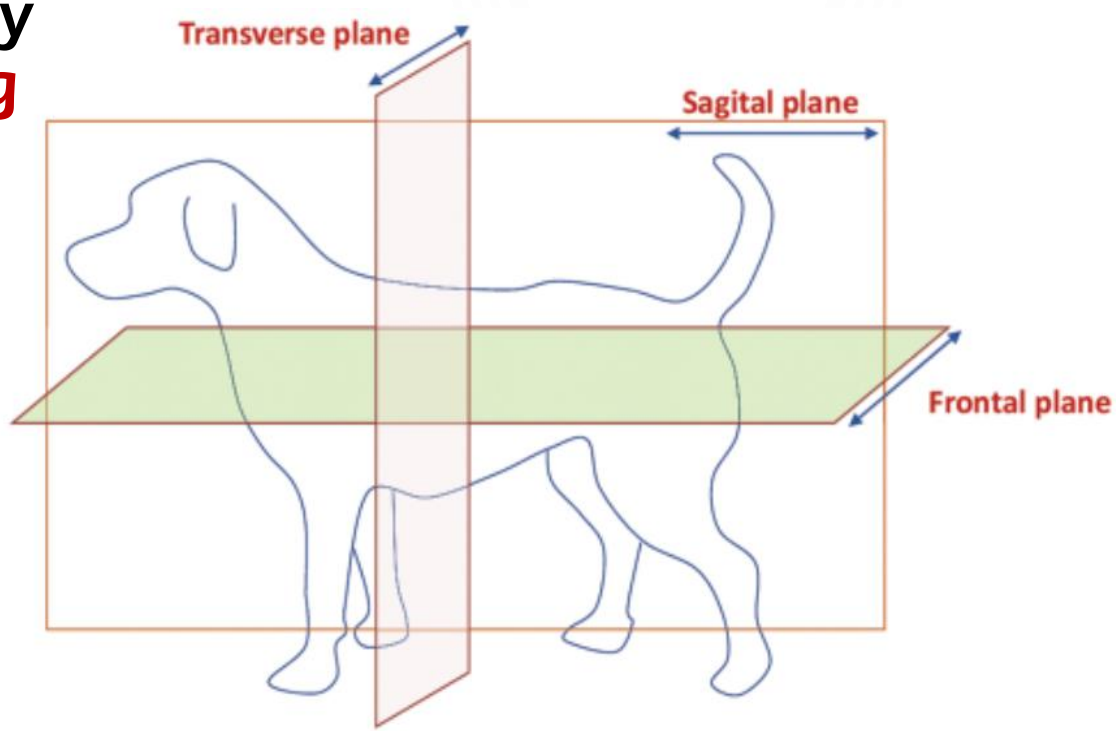
The Basics of the ECG in 5min

CMFT ugme

undergraduate medical education

Electrocardiographic Leads

- Several sets of electrodes are used in clinical electrocardiography to study the flow of electricity through the heart in the different anatomical planes. These are called the electrocardiographic leads.
- Each lead interrogates the flow of electricity in a specific direction as if we were 'viewing the heart from different perspectives'.
- By combining the information given by all leads, the propagation of electricity can be studied in all three dimensions.
- Two main lead systems are used:
  - Hexaxial system
  - Precordial system.



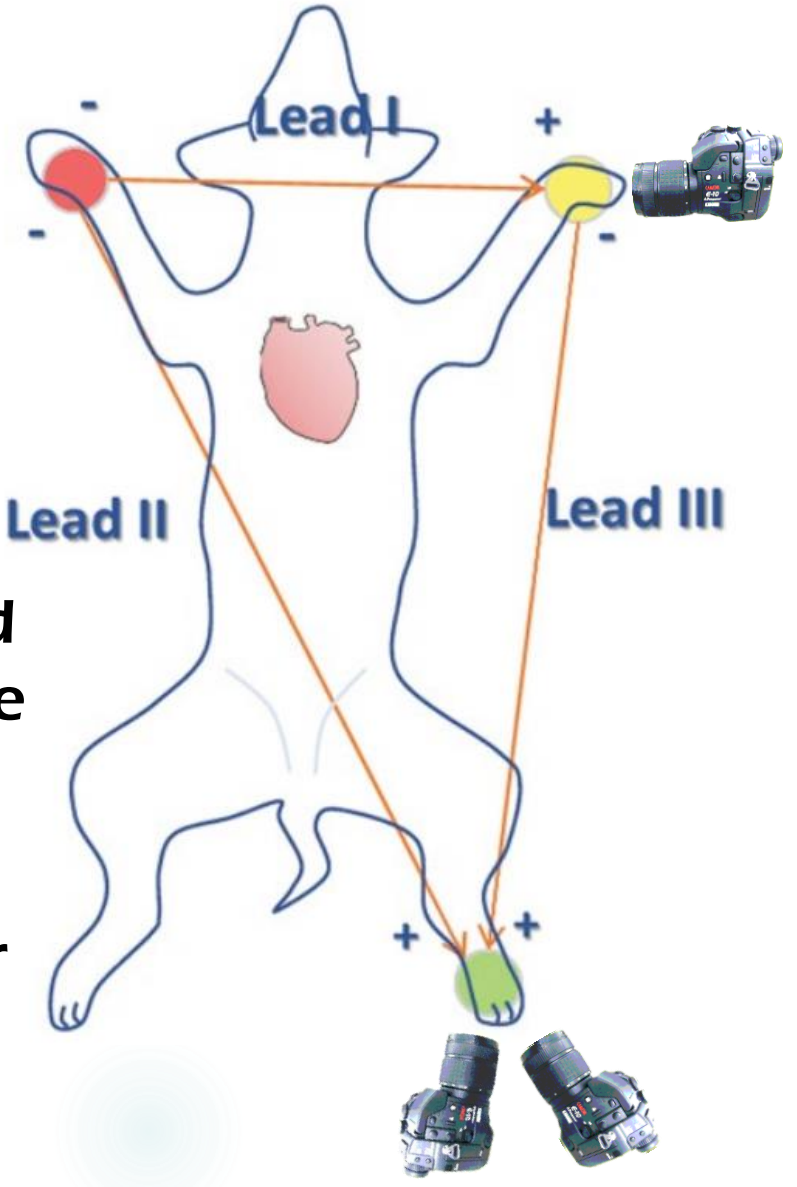
The Hexaxial System

II

- Is the most commonly used lead system.
  - It allows the assessment of electrical activity in the frontal plane
  - As the name indicates, it includes six distinct leads

Bipolar, or Standard, Limb Leads

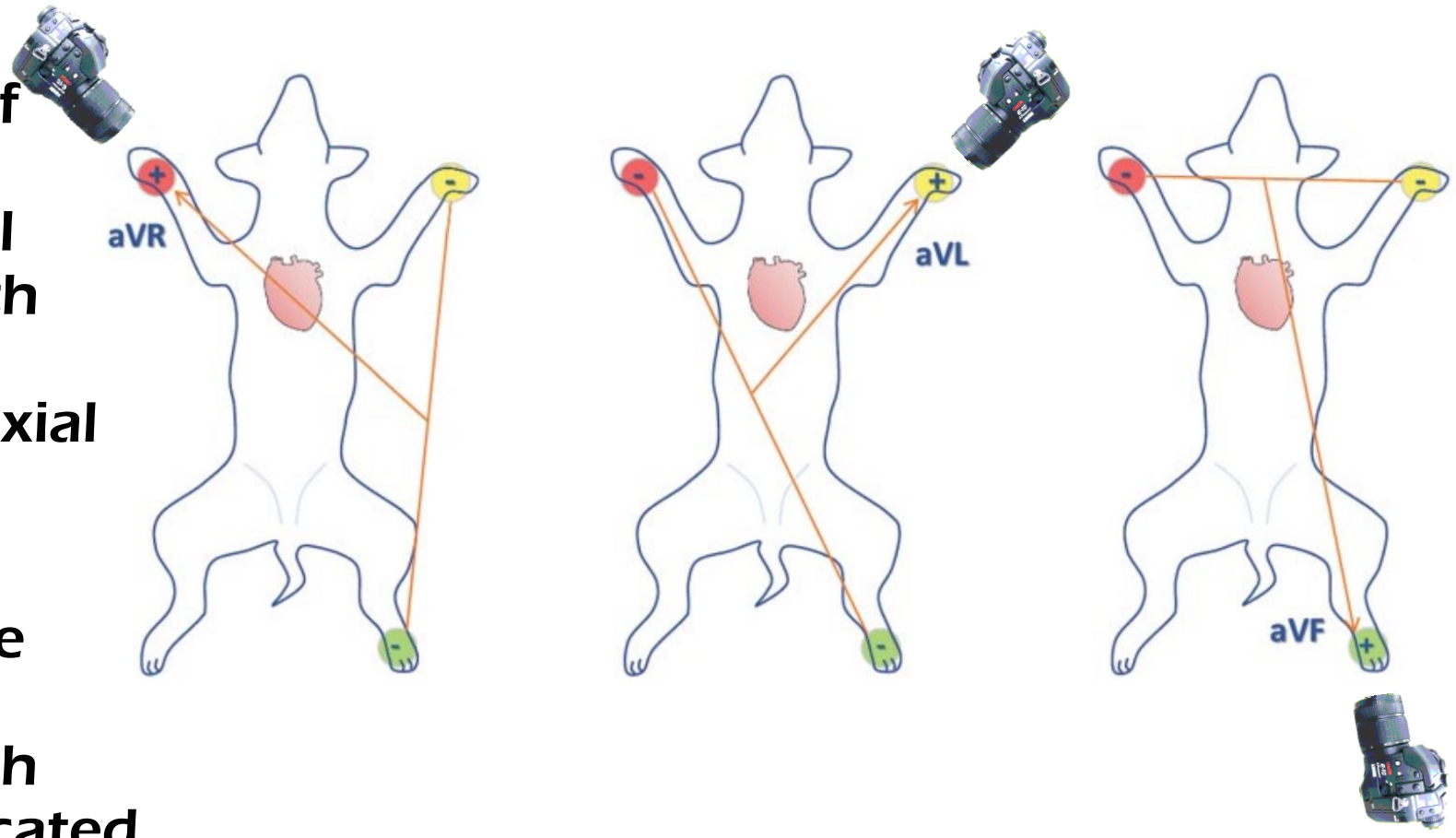
- Leads I, II and III were the first leads to be used in clinical practice in the early 1900s. They were devised by the Dutch physiologist Willem Einthoven and have been in use ever since.
- By positioning one electrode on each forelimb and a third electrode on one of the hindlimbs, three bipolar leads are obtained forming an inverted triangle with the heart at the center – Einthoven's triangle



The Hexaxial System

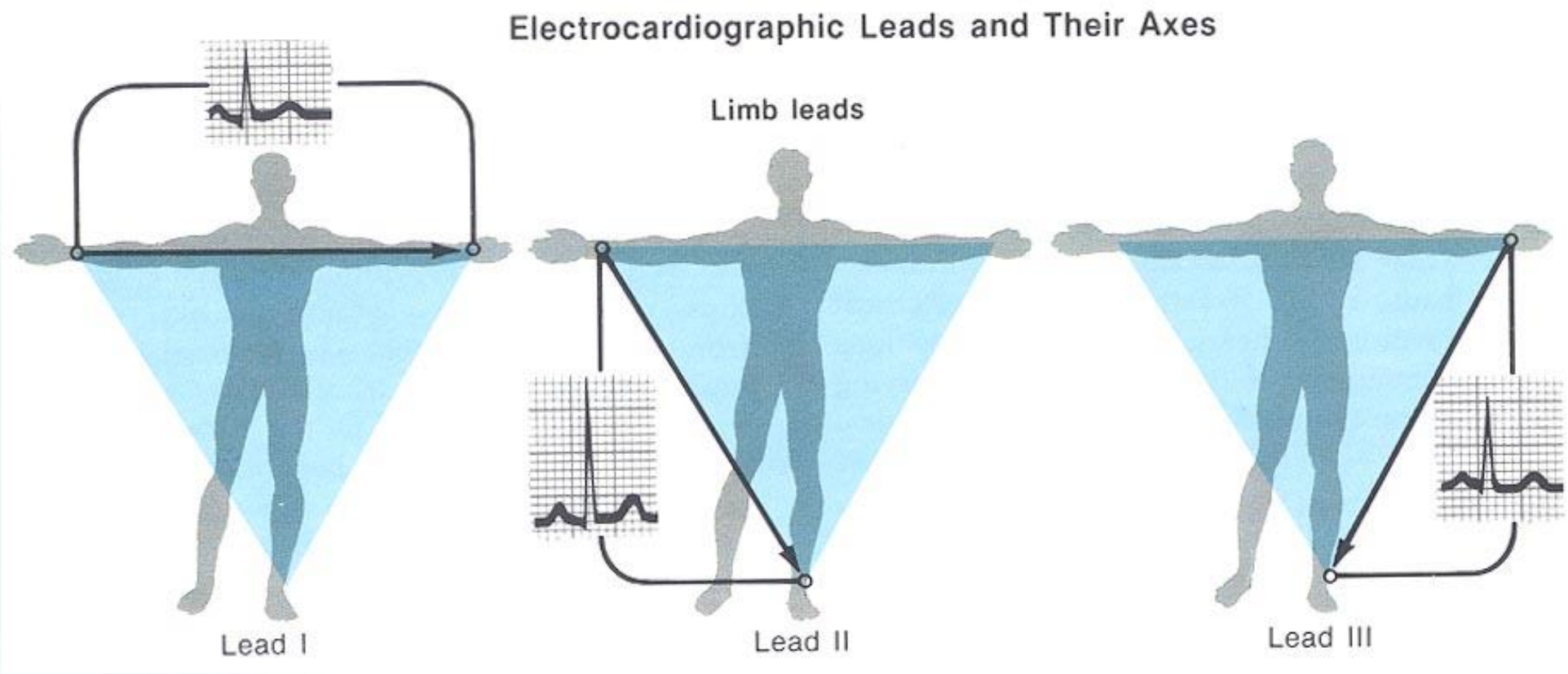
Unipolar Limb Leads

- To increase the number of '*viewing perspectives*' available, three additional leads were integrated with Einthoven's bipolar lead system to create the hexaxial system.
- These are the *augmented unipolar leads* and use the same limb electrodes as described earlier, although they do not use two dedicated electrodes like the bipolar leads



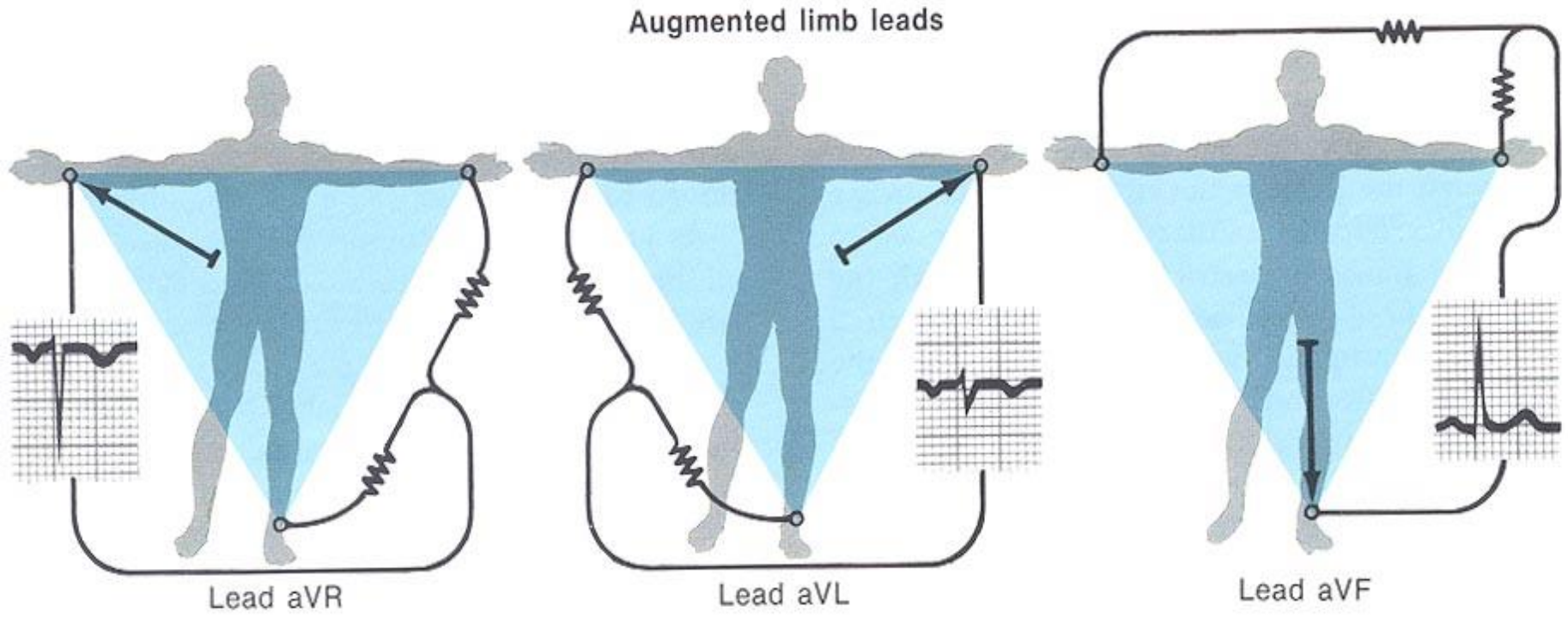
The Hexaxial System

Bipolar, or Standard, Limb Leads in Human



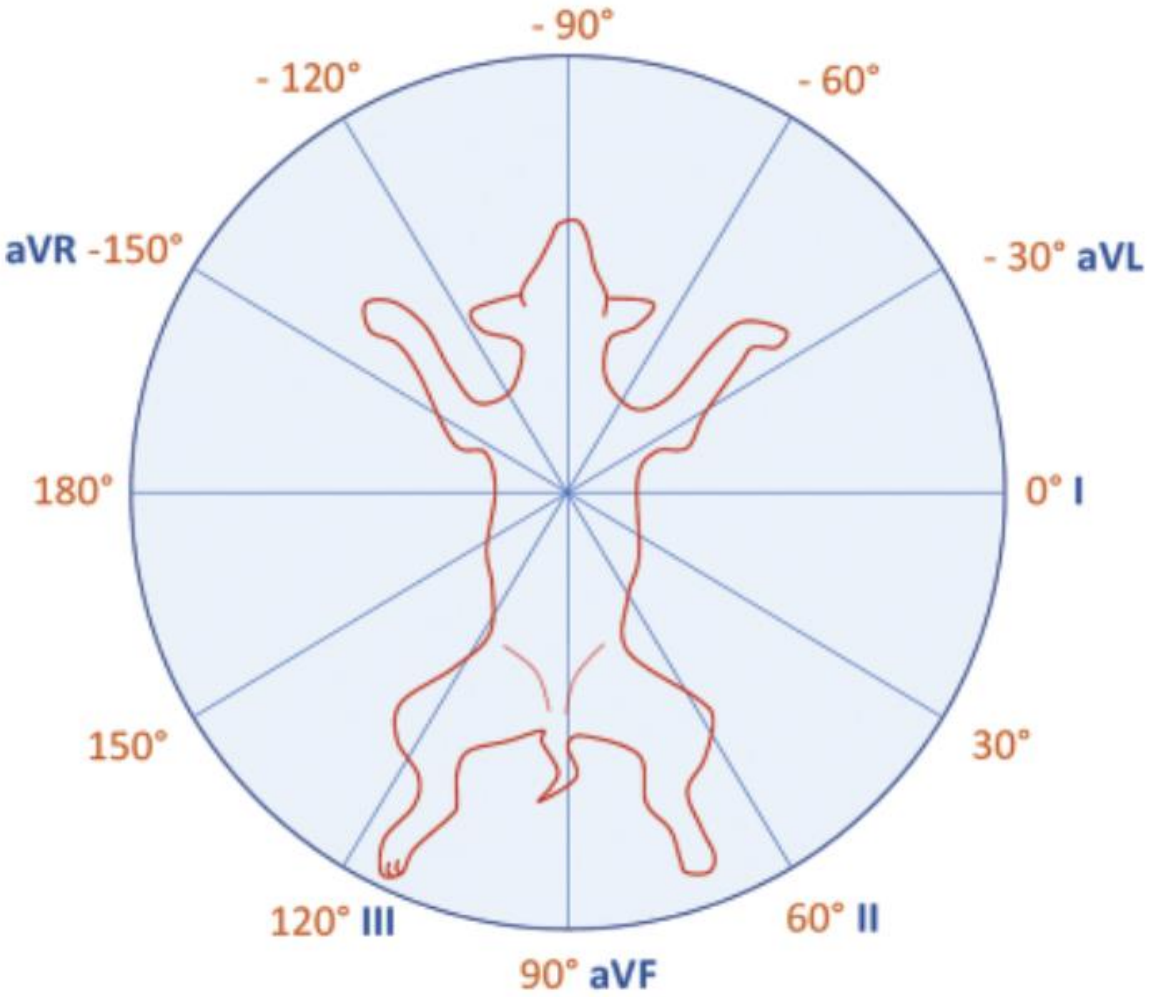
The Hexaxial System

Unipolar Limb Leads in Human



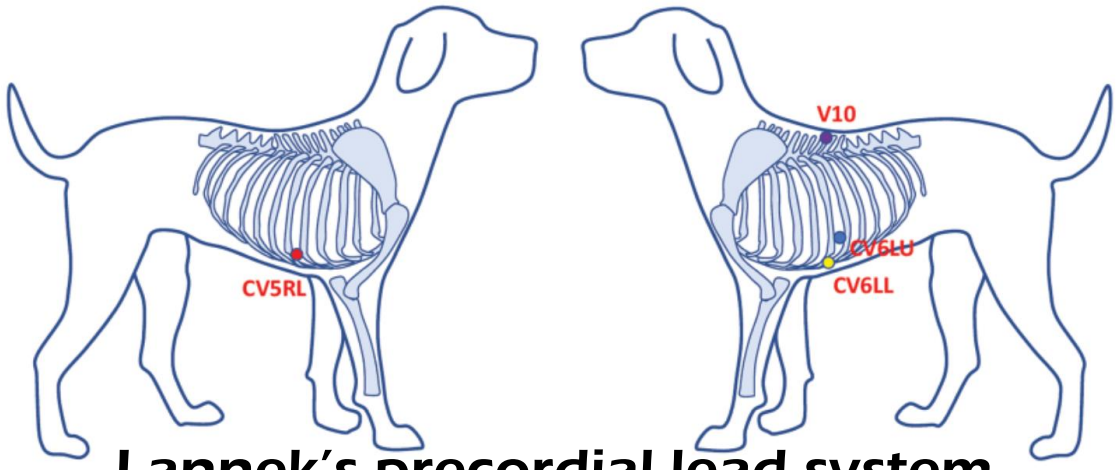
The Hexaxial System

- The combination of the bipolar and unipolar augmented leads forms the hexaxial system that allows the study of the electricity flow in the frontal plane.
- The diagram illustrates the possible directions of electricity flow measured in angles.
- The location of the name of the lead corresponds to the position of the exploring electrode (+). This diagram is used to calculate the mean electrical axis of the heart (MEA) that represents the average of the sum of all vectors during ventricular (or atrial) depolarisation

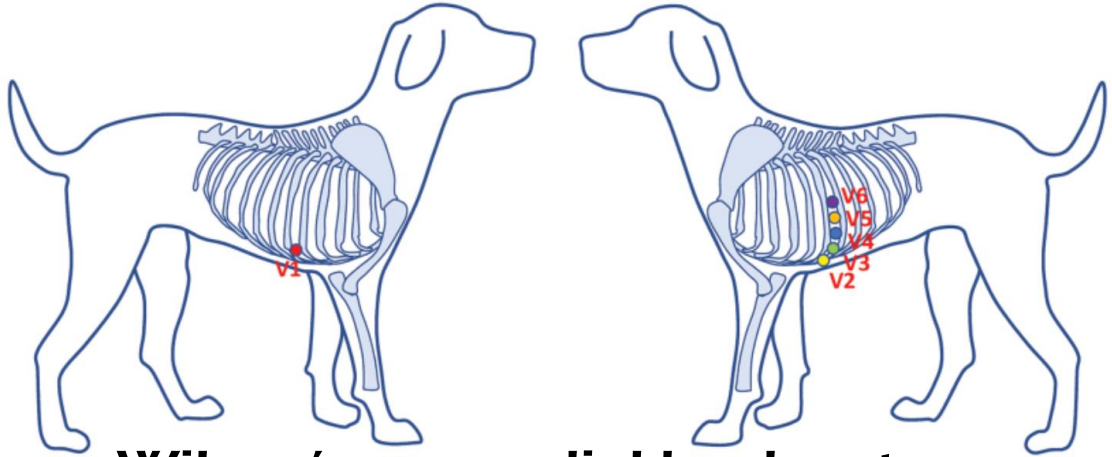


The Precordial System

- The precordial lead system assesses the flow of electricity on the transverse or horizontal plane. The exploring electrode (positive) is positioned in specific locations on the chest and the Wilson's central terminal (WCT) is used as the reference electrode (negative).
  - More than one precordial lead system has been described in dogs; however, the large variation in chest conformation among breeds makes it difficult to find a system that offers repeatable results for all individuals of this species.



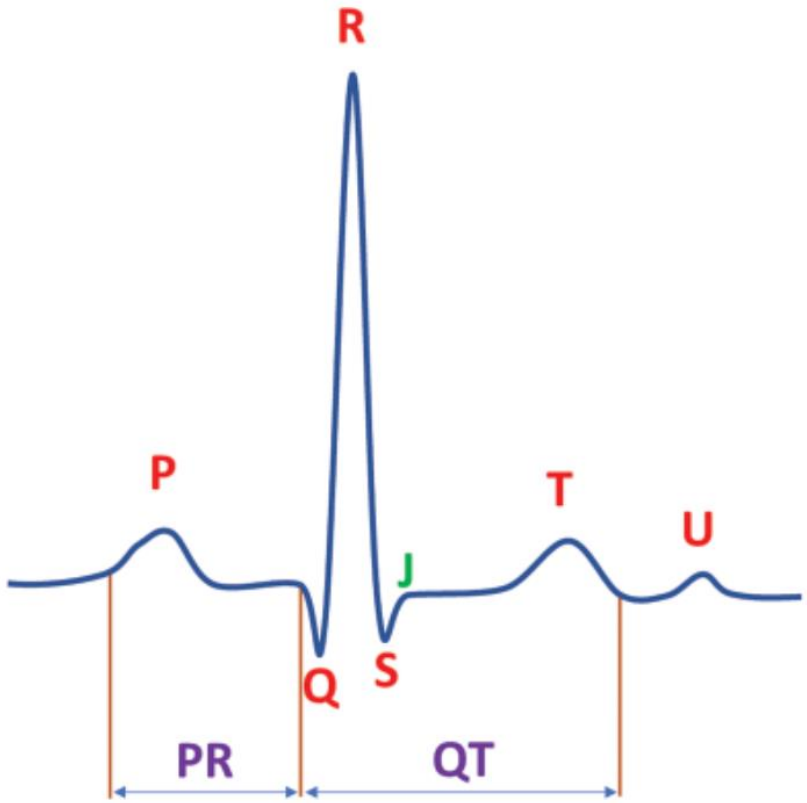
Lannek's precordial lead system



Wilson's precordial lead system

Genesis of the Electrocardiogram

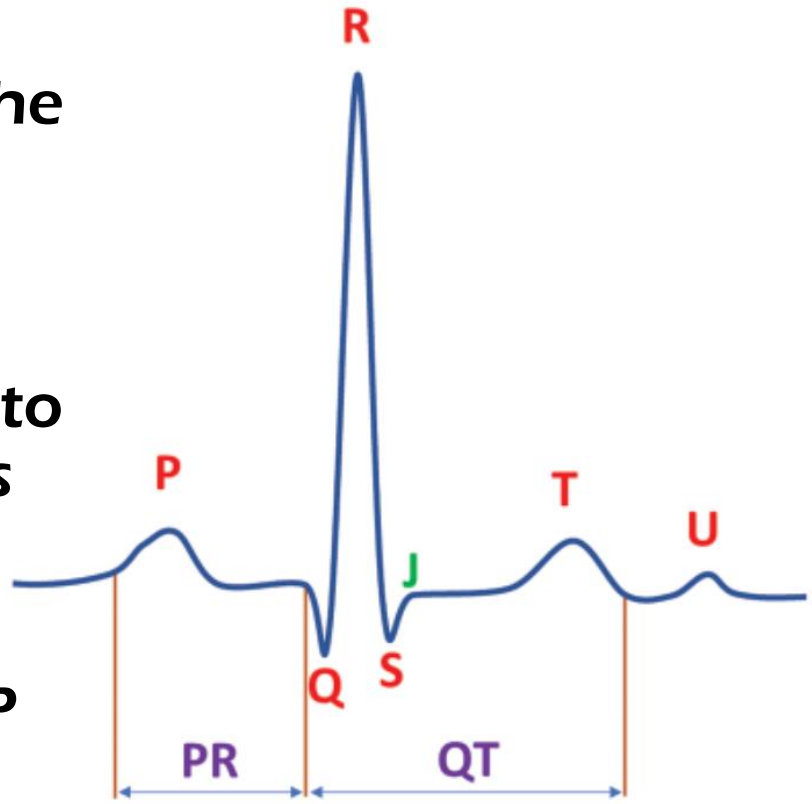
- The P wave represents atrial depolarisation.
- The Q, R and S waves together form the QRS complex that represents ventricular depolarisation.
  - The J point represents the return to baseline after the QRS.
- The T wave is the result of ventricular repolarization.
  - U wave (normally not visible) is attributed to delayed repolarisation of the Purkinje or M cells of the myocardium.



Genesis of the Electrocardiogram

II

- Between each wave, there is a return to baseline called a segment.
- The PR segment, from the end of the P wave to the beginning of the QRS, represents the time the impulse spends travelling through the AVN and His-Purkinje.
- During the ST segment, from the end of the QRS to the beginning of the T wave, the myocardial cells are in stage 2 of the action potential, and actual contraction is occurring.
- The PR interval starts from the beginning of the P wave to the beginning of the QRS.
- The QT interval from the beginning of the QRS until the end of the T wave.

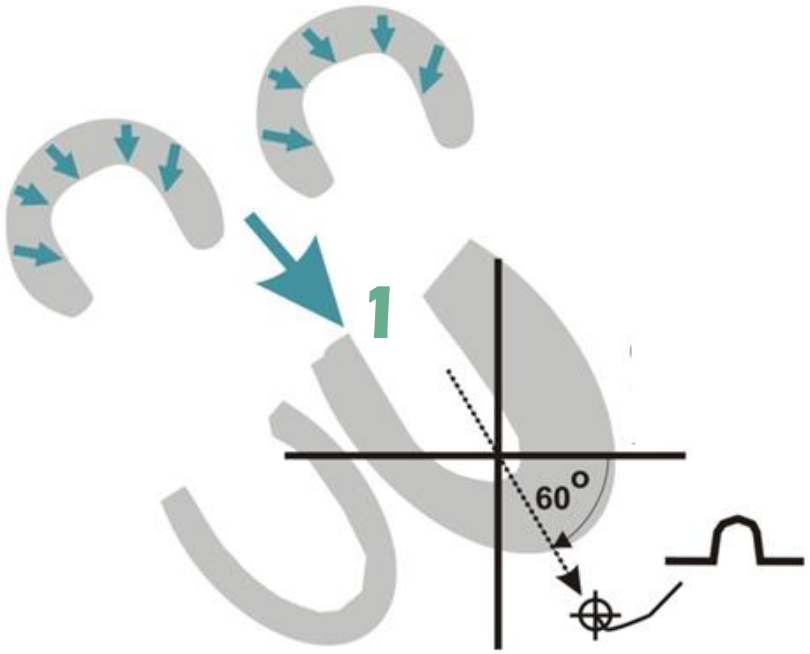


Cardiac Electrical Events

II

1. Atrial Depolarisation:

- Atrial depolarisation proceeds from the top of the atria downward in all directions.
- Summing these vectors of depolarization results in the main atrial depolarisation vector oriented as shown (large green arrow). It is moving towards the positive electrode of the lead II, resulting in an upward deflection of the ECG.
- Since the atrial muscle action potential is slow, relative to that of the ventricular myocardium the P-wave inscription is "rounded" instead of a spike.



Cardiac Electrical Events

II

2. **Septum Depolarisation:**

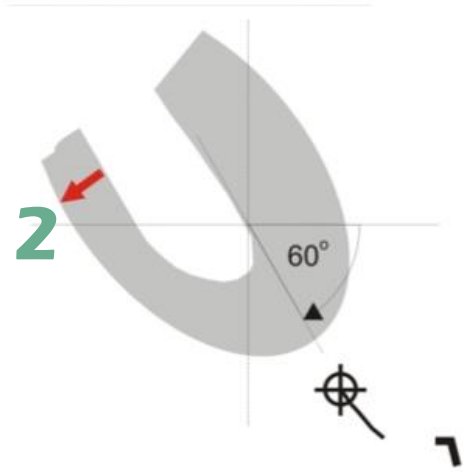
- Septum depolarises from the inside out and the resulting depolarisation wave moves away from the electrode recording Lead II.

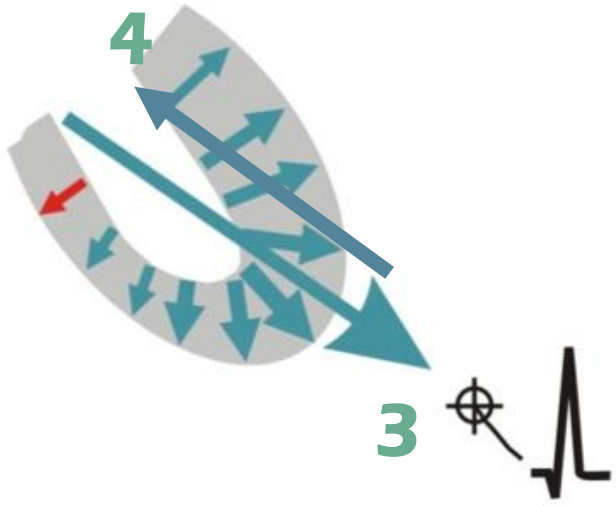
3. **Apex Depolarisation:**

- Depolarisation wave then move fast toward the apex of the heart causing a positive spike deflection in Lead II

4. **Base Depolarisation:**

- The base of the ventricle depolarizes after apex depolarisation creates another cardiac vector which is in opposite direction of the 3rd cardiac event.
  - The algebraic sum of all of the small depolarisation vectors in a normal heart, almost always moving directly toward Lead II, generating a mostly positive QRS complex



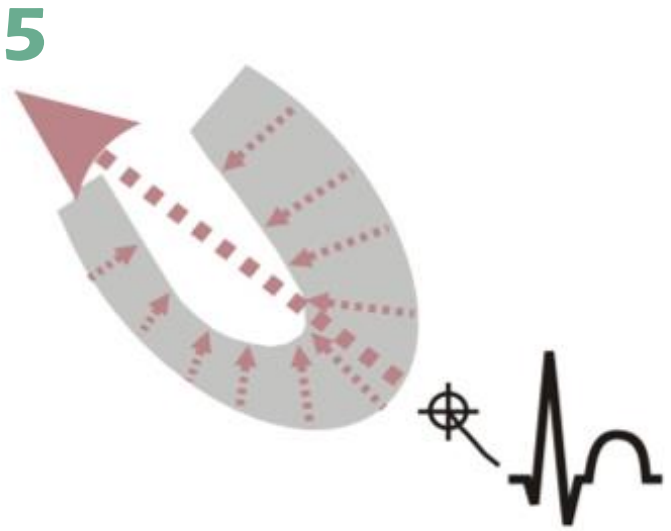


Cardiac Electrical Events

II

5. Ventricular Repolarisation:

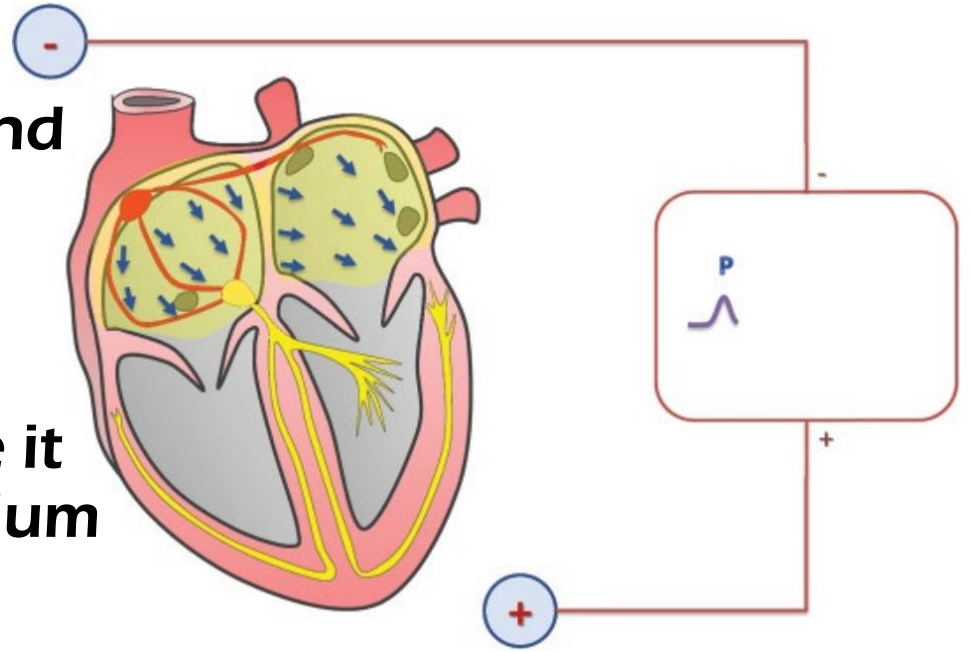
- The repolarisation process proceeds at a much slower rate than depolarisation so the wave inscribed (T-wave) is wide and rounded.
- The repolarization vector is moving from the Lead II electrode (from apex to base) so the inscribed T-wave is always positive.



The P wave

II

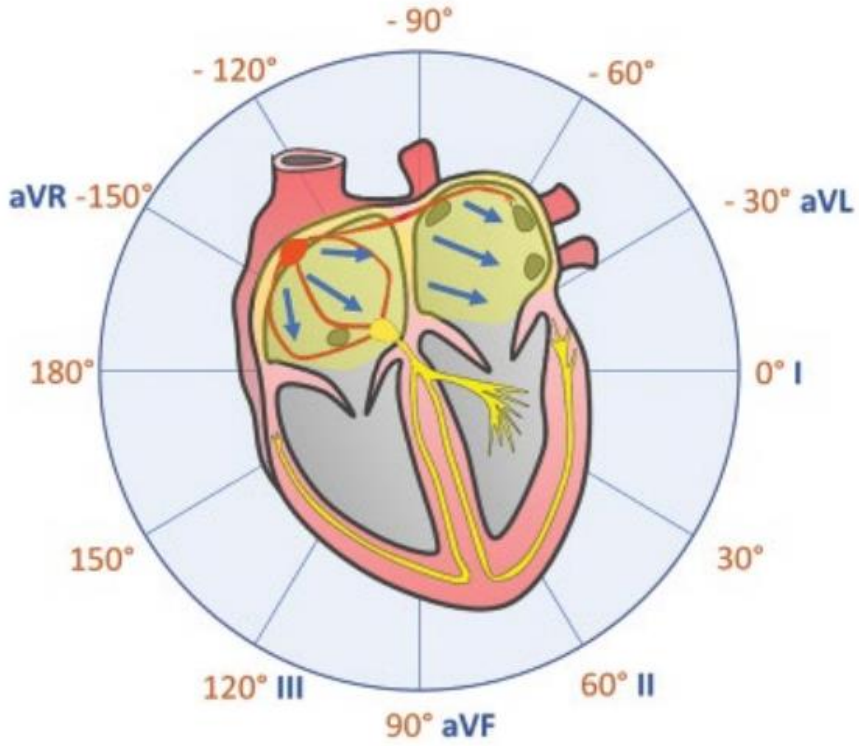
- Represents atrial depolarisation.
- Starts in the sinus node and travels "downwards" and towards the left
- Positive in leads II, III and aVF (inferior leads) and negative in leads aVL and aVR
  - In lead I it may appear as a positive, biphasic or isobiphasic
- The duration of the P wave represents the time it takes for both the right and left atrial myocardium to be completely depolarised.
- Its amplitude is directly proportional to the atrial mass which is why the P wave is smaller in comparison to the QRS and why an increase in amplitude suggests atrial enlargement

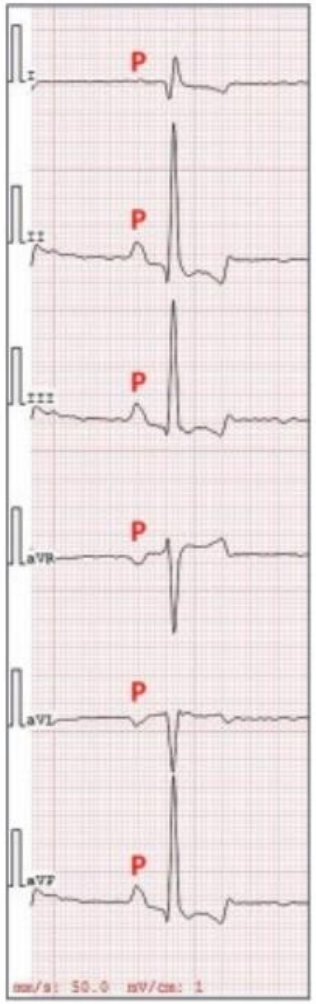


The P wave

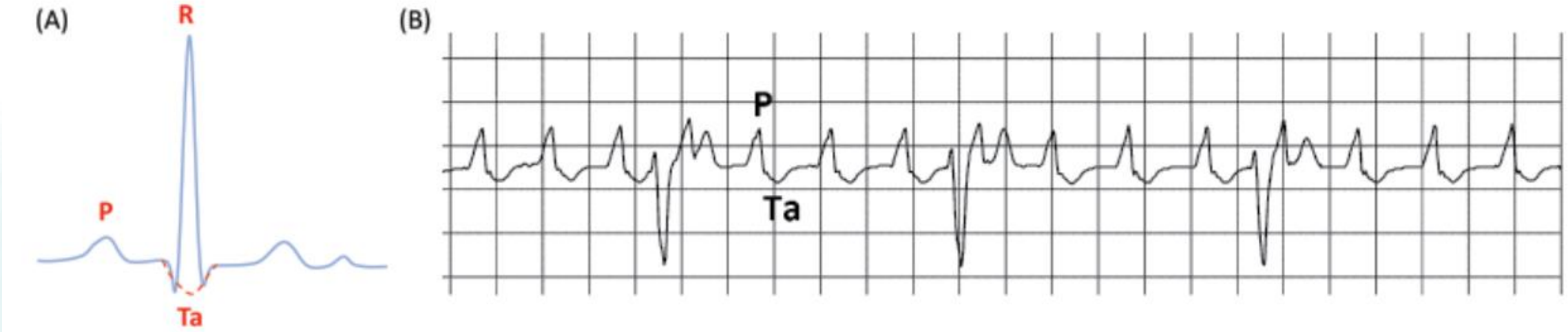
II

- Atrial depolarisation and the appearance of the P wave in all six leads.
- The P wave is positive in leads II, III and aVF (inferior leads) and negative in leads aVL and aVR.
- In lead I, it may appear as a positive, biphasic or isobiphasic wave.





T_a wave

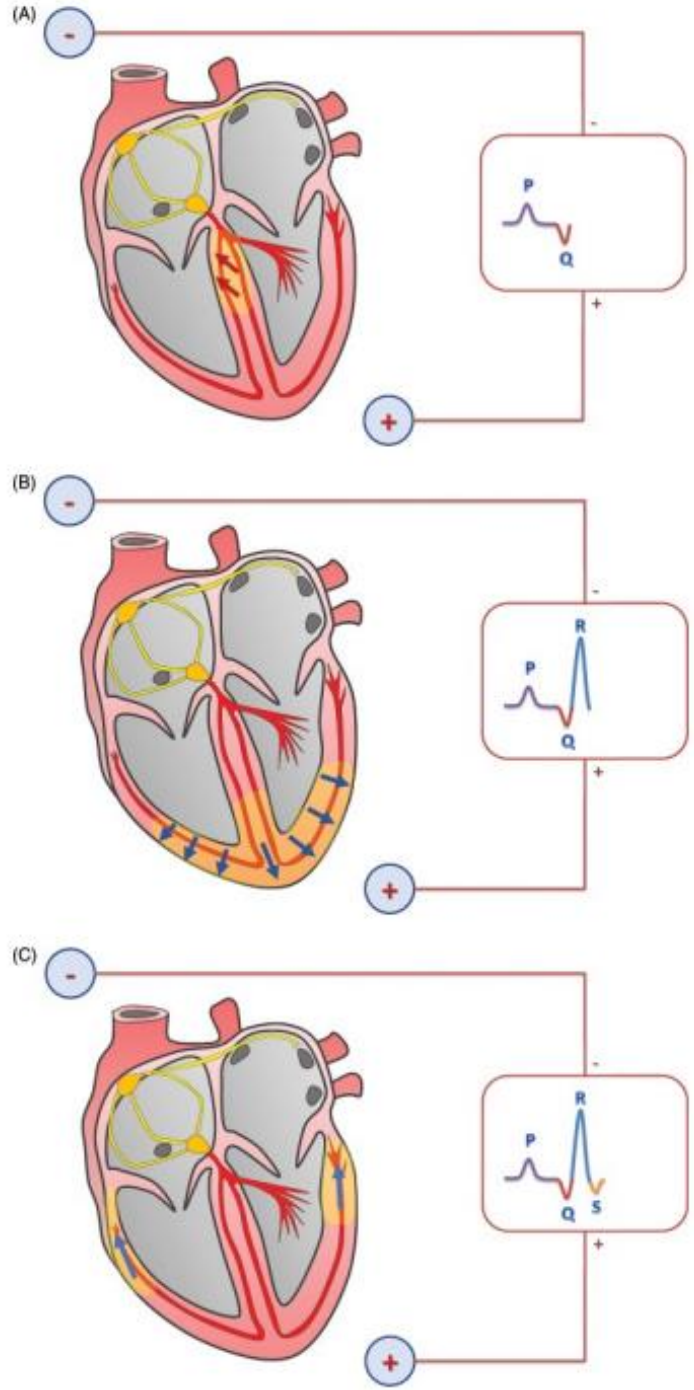


(A) Atrial repolarisation occurs at the same time as the QRS, and therefore the T_a is not normally visible. (B) Holter recording showing non-conducted P waves where the T_a can be seen. [10-year-old, female neutered Greyhound dog with third-degree atrioventricular block]

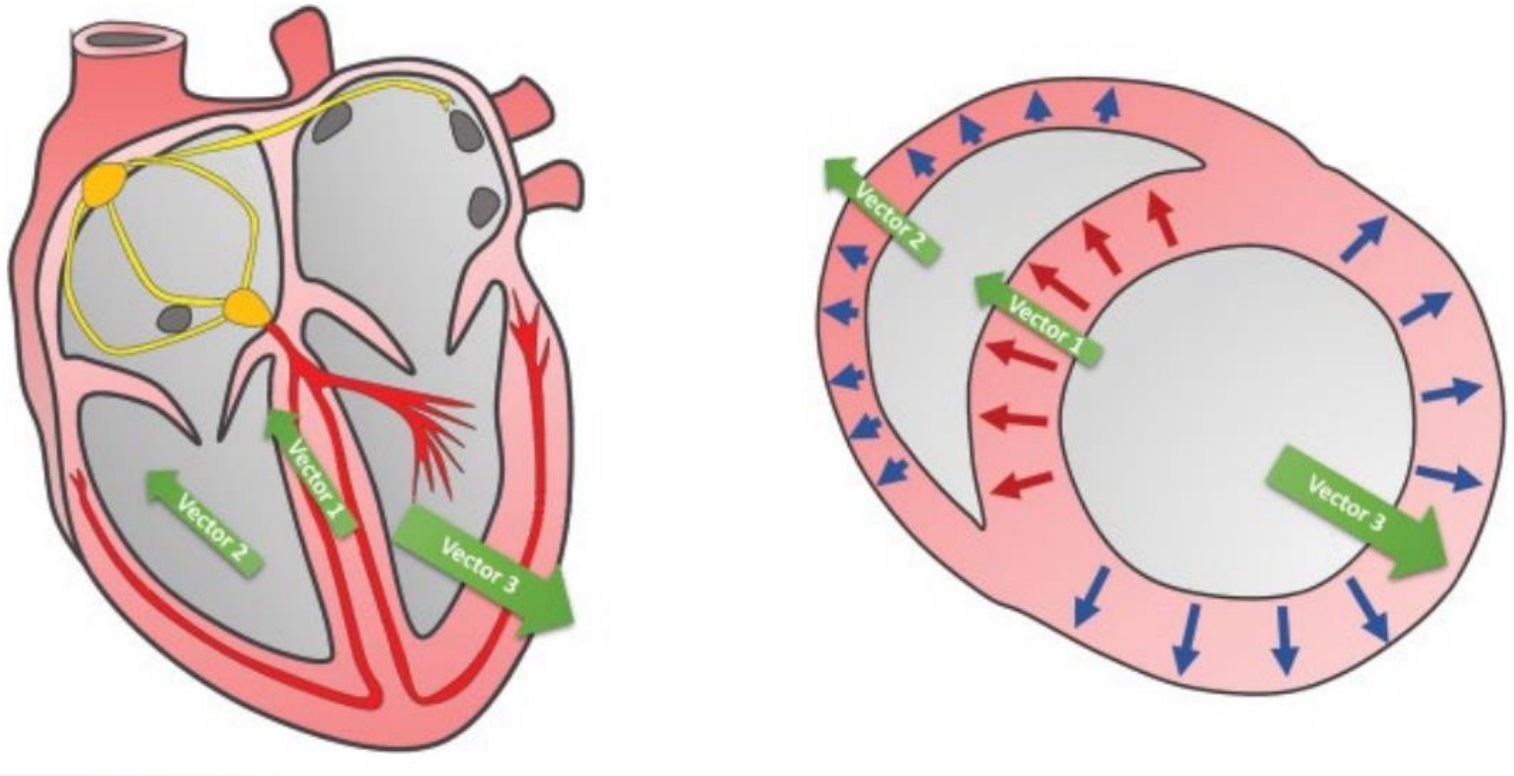
The QRS Complex

Ventricular depolarisation.

- (A) The left side of the septum is depolarised, creating a depolarisation wave upwards towards the right (arrows). This is recorded as negative deflection in lead II – the **Q wave**.
- (B) The free walls of both ventricles are depolarised next from the apex towards the base. The sum of the depolarisation vectors is recorded as a positive deflection in lead II – the **R wave**.
- (C) Finally, the base of the ventricles is activated with a depolarisation vector directed upwards. This may be recorded as a negative deflection in lead II – the **S wave**



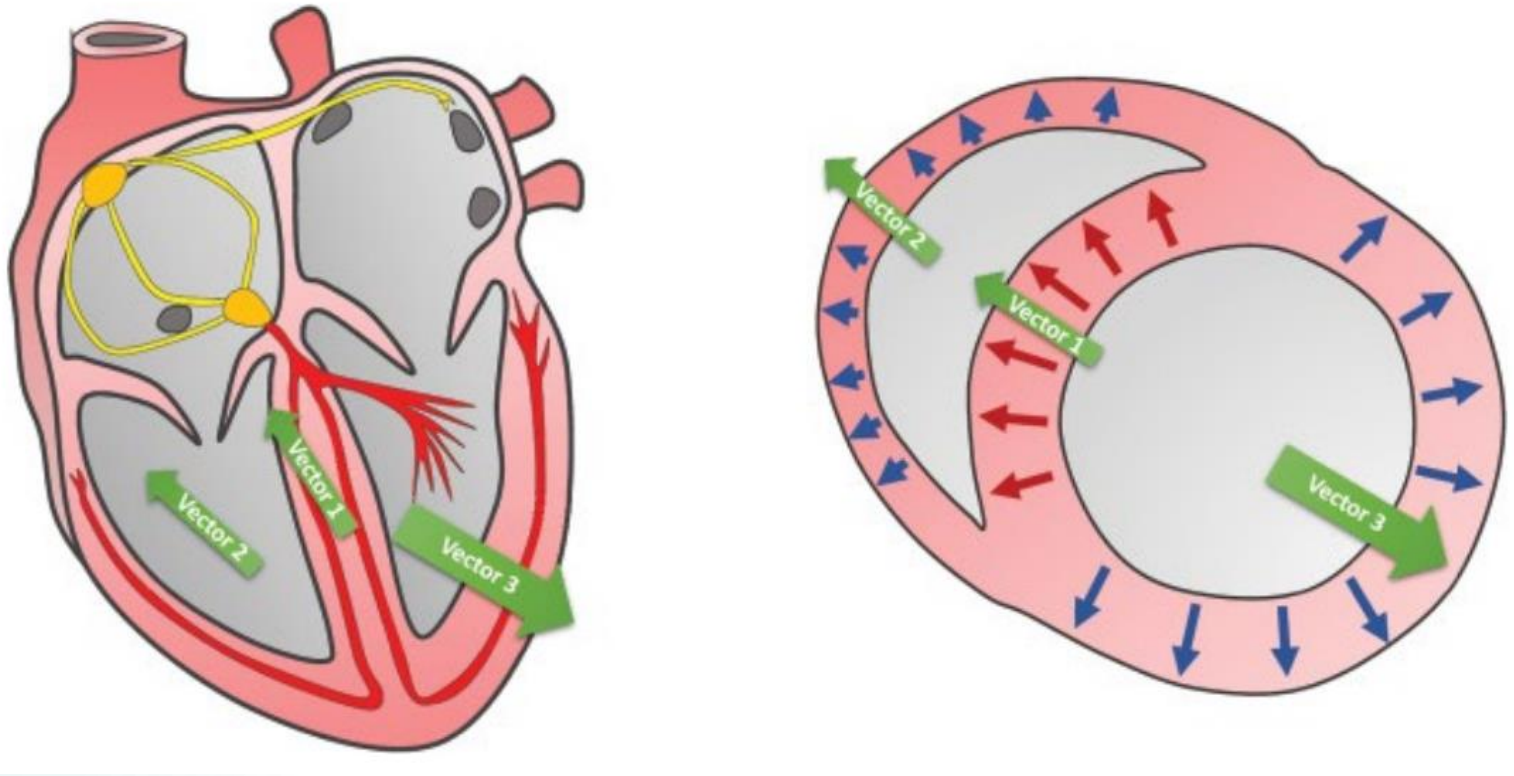
The QRS Complex



Representation of the main cardiac vectors resulting from the propagation of the wavefronts through the ventricles.

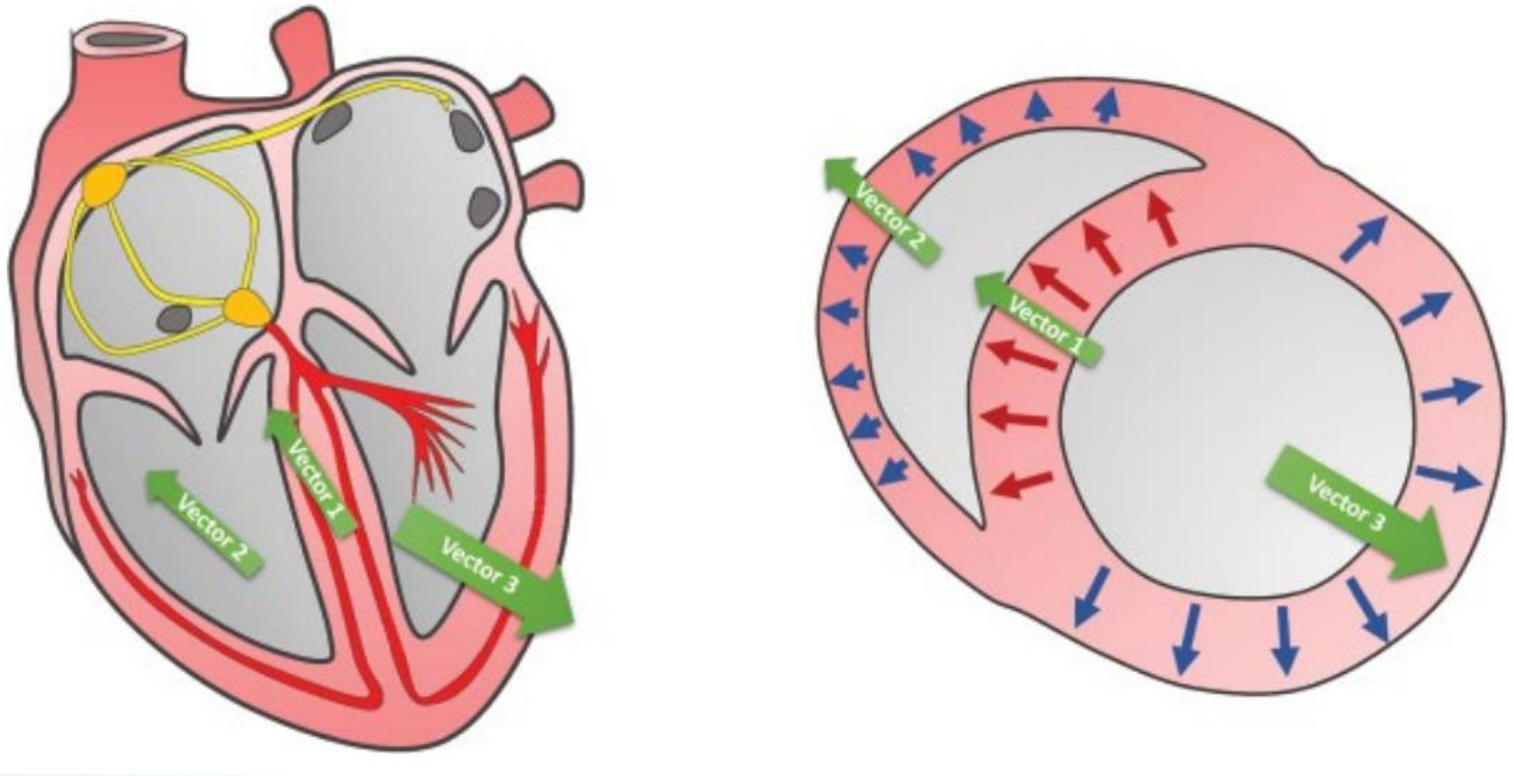
- **Vector 1:** The left side of the interventricular septum is depolarised first (≈5ms) via divisions of the left bundle branches, and is followed by the right side of the septum (≈12ms). This results in an initial depolarisation front travelling 'upwards' (caudal-to-cranial/ventral-to-dorsal) and towards the right.

The QRS Complex



- **Vector 2:** The impulse then reaches the apex of the ventricles (≈15–25ms) and the base (≈40–45ms) via the right and left bundles. The depolarisation wave travelling through the right ventricle has an 'upwards' (caudal-to-cranial/ventral-to-dorsal) direction and towards the right.

The QRS Complex

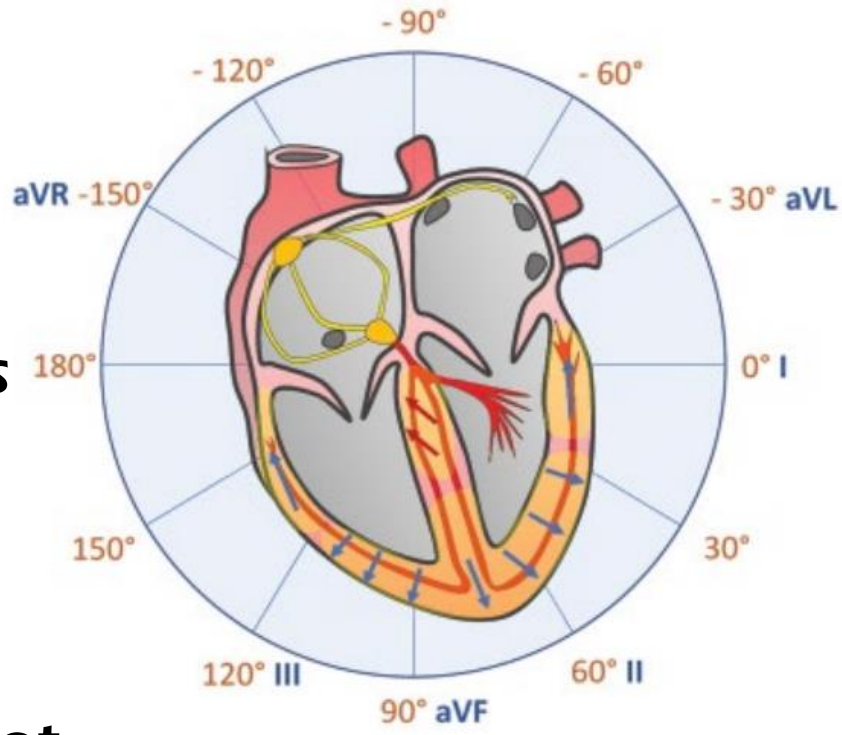


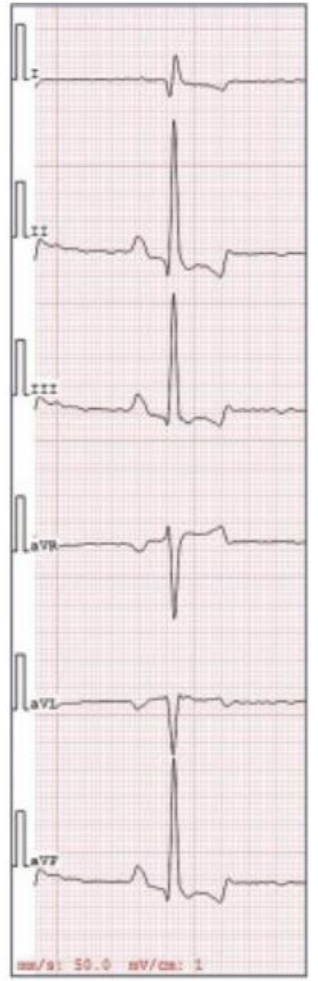
- **Vector 3:** Activation of the left ventricle occurs via the branches of the cranial (anterior) and caudal (posterior) fascicles. Synchronous activation of the left ventricular areas supplied by both fascicles results in a depolarisation vector travelling with a 'downwards' (cranial-to-caudal/dorsal-to-ventral) direction and towards the left.

The QRS Complex

II

- Depolarisation of the interventricular septum (vector 1 – red arrows) results in an initial depolarisation front travelling 'upwards' (caudal-to-cranial/ventral-to-dorsal) and towards the right.
- In leads I, II, III and aVF of the electrocardiogram (ECG), this appears as an initial negative deflection called the Q wave, although it is not always visible.
- In aVR it appears as a small positive wave (R instead of Q). In aVL it may not be visible or may appear as either a small negative or positive wave.

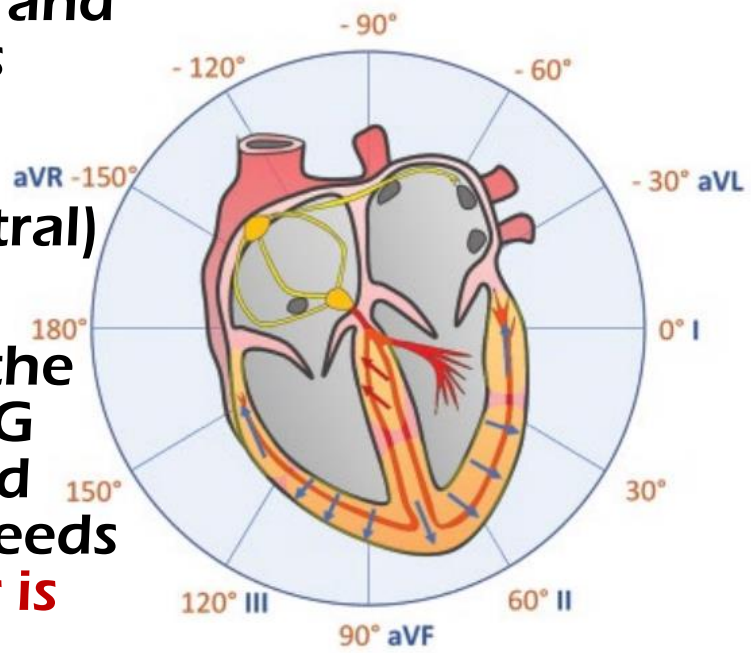


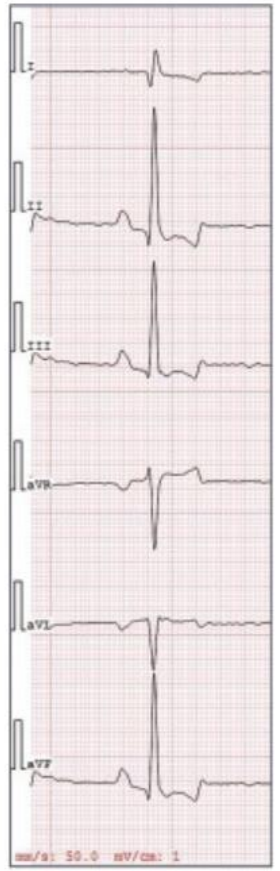


The QRS Complex

II

- The depolarisation wave travelling through the right ventricle has an 'upwards' (caudal-to-cranial/ventral-to-dorsal) direction and towards the right (vector 2), and synchronous activation of the left ventricle results in a depolarisation vector travelling with a 'downwards' (cranial-to-caudal/dorsal-to-ventral) direction and towards the left (vector 3).
- Given that both ventricles are depolarised at the same time, the next wave recorded on the ECG corresponds to the sum of vectors 2 and 3, and since the mass of the left ventricle greatly exceeds that of the right ventricle, the resulting vector is directed 'downwards' (cranial-to-caudal/dorsal-to-ventral) and towards the left.
- In leads I, II, III and aVF, this results in a positive deflection – the R wave. In leads aVR and aVL, it appears as a negative deflection (S instead of R)

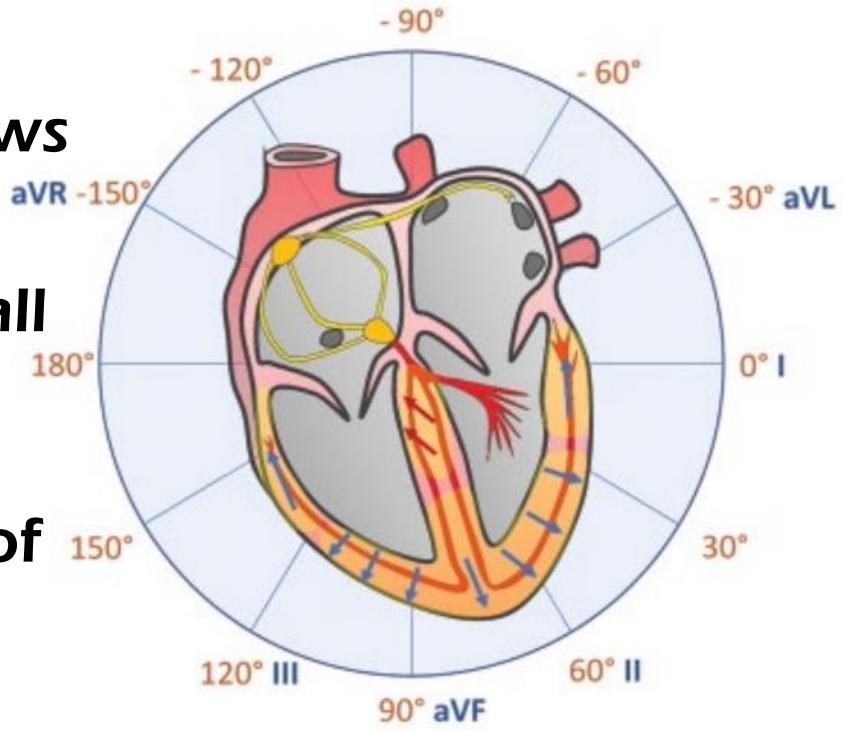


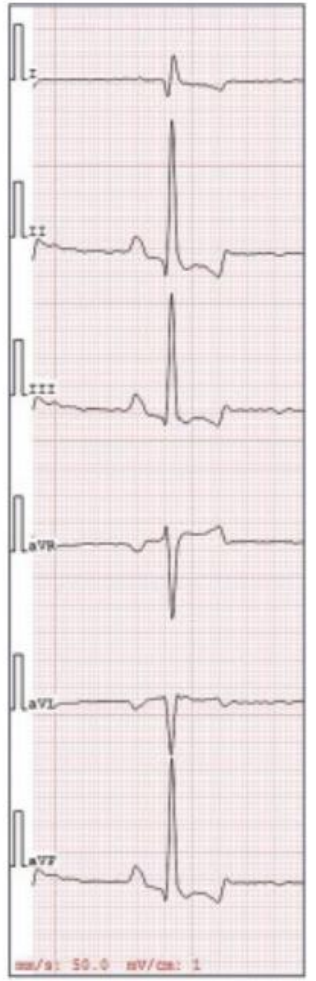


The QRS Complex

II

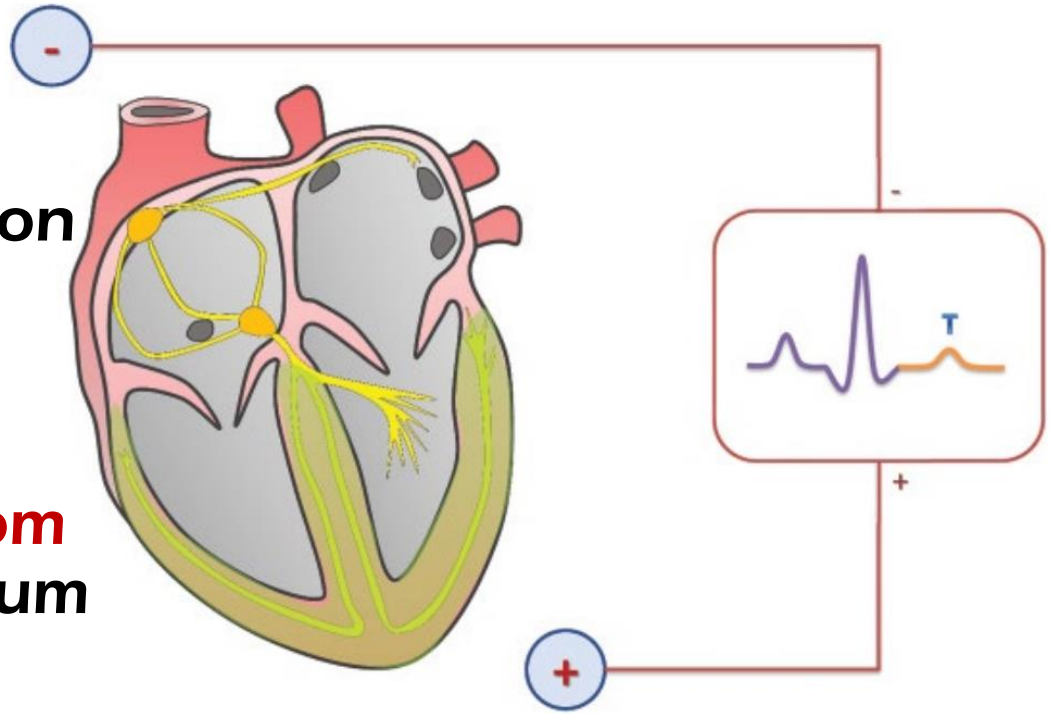
- The base of the ventricles is the last to be depolarised, resulting in a fourth vector directed 'upwards' (caudo-dorsally; upward blue arrows at ventricle base).
- In humans, this may result in a small negative deflection on the ECG called the S wave. However, in quadruped animals, the direction of this vector is perpendicular to the frontal plane and is often not recorded on the hexaxial system.





The T Wave

- Represents ventricular repolarisation
- Cells are undergoing stage 3 of the action potential with a progressive return to the resting membrane potential.
- The epicardial cells achieve full repolarisation before the endocardial cells, creating an electrical dipole that is recorded as a deflection on the ECG – a T wave
- The overall direction of repolarisation is from the apex to the base and from the epicardium to endocardium.
- In both dogs and cats, the appearance of the T wave is variable and can occur as a positive, negative or biphasic deflection in normal subjects

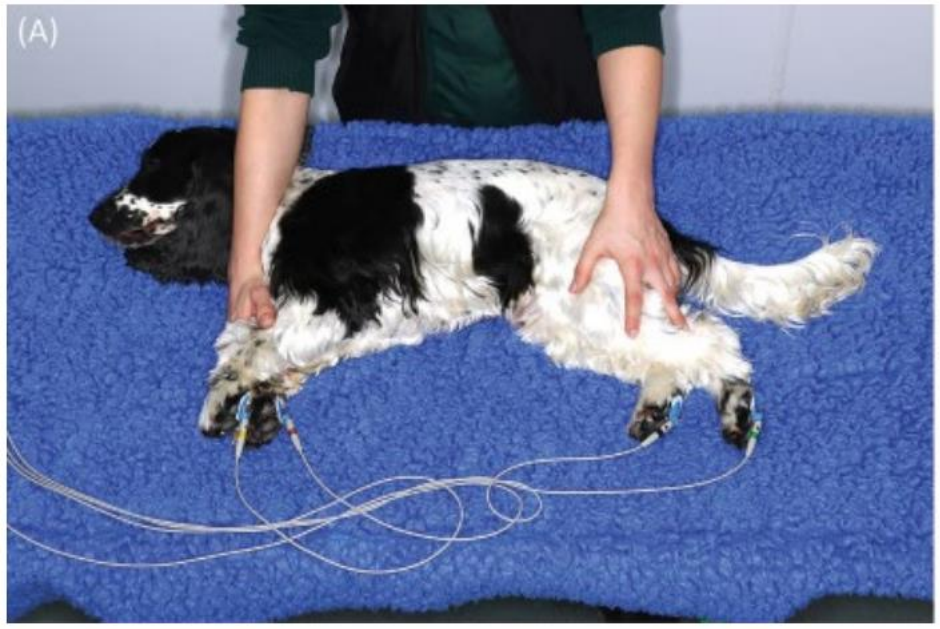


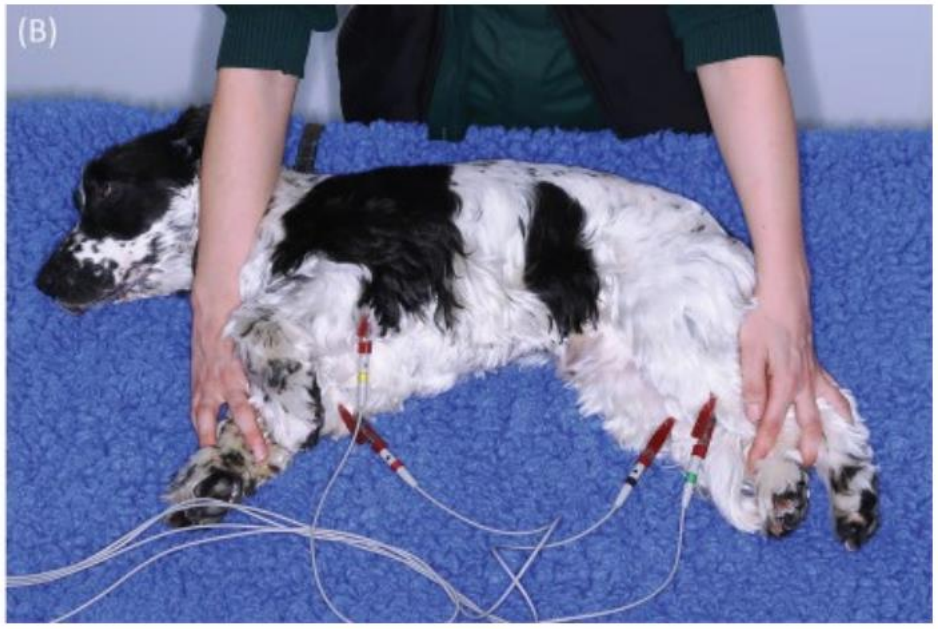
Heart Conduction System

Section III

Performing an Electrocardiography

Diagnostic Resting ECG Trace in a Dog



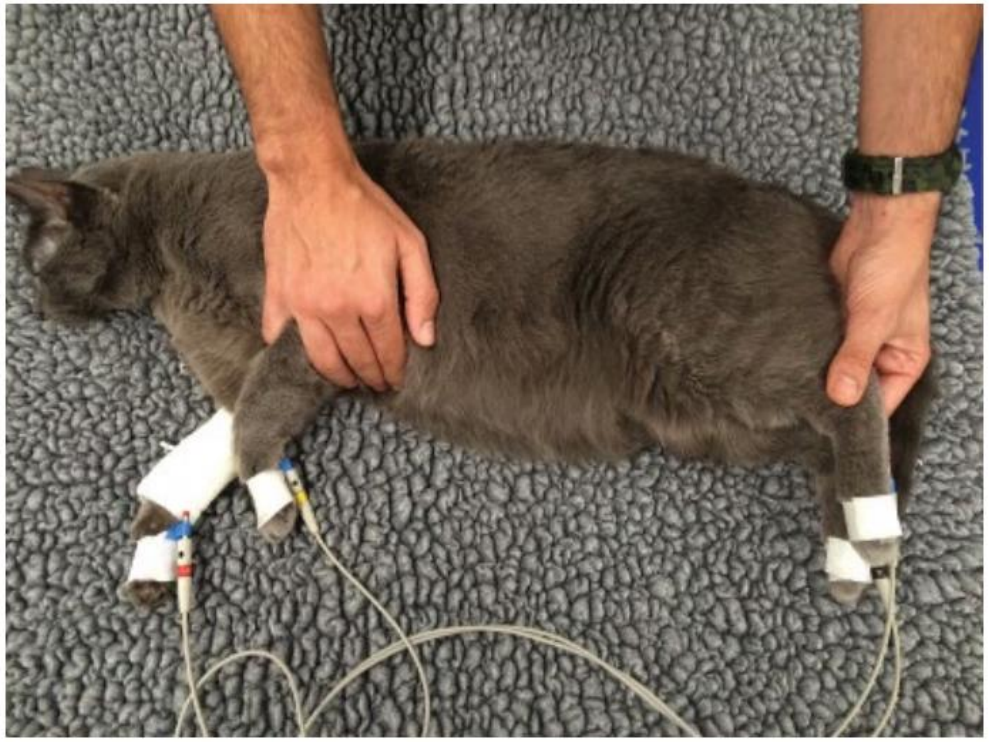


- (A) Adhesive electrodes can be attached to the digital pads or metacarpal/metatarsal pads.
- (B) If 'crocodile' clips are used, they can be placed on the skin over the olecranon in the forelimbs and over the patellar tendon in the hindlimbs.
- During a standard examination, the patient should always be in right lateral recumbency

Diagnostic Resting ECG Trace in a Dog

- The ECG cables are attached to the skin using either pre-gelled self-adhesive electrodes attached to the digital pads or metacarpal and metatarsal pads, or crocodile clips with the ends smoothed or slightly bent to avoid them pinching the patient
- If crocodile clips are used, electrical contact is generally achieved using alcohol (Caution – flammable!) on the clips or, less commonly, an ECG gel.

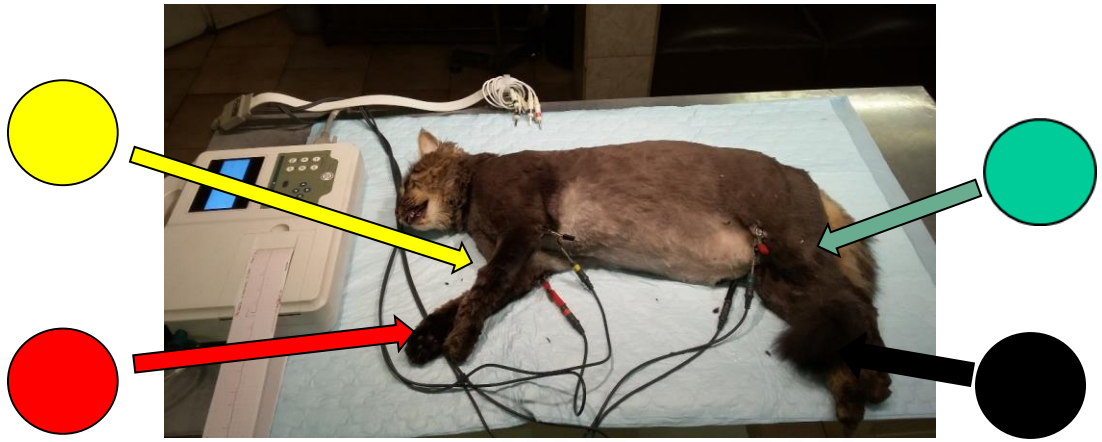
Diagnostic Resting ECG Trace in a Cat

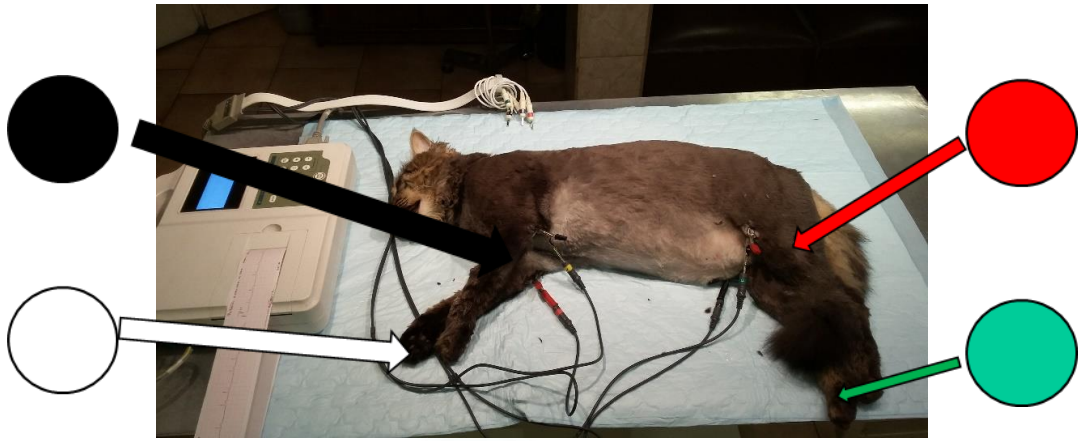


- Ideally, cats are also gently restrained in right lateral recumbency for ECG recording
- Purring can be a cause of baseline artefact
  - avoiding stroking the cat during the procedure
  - holding a small piece of cotton wool soaked in alcohol or antiseptic hand gel close to the cat's face

Standard limb positions and electrode colors

Electrode	Lead colour in Europe	Lead colour in the USA	Position
Right forelimb	Red	White	On skin over right olecranon
Left forelimb	Yellow	Black	On skin over left olecranon
Left hindlimb	Green	Red	On skin over left patellar tendon
Right hindlimb	Black	Green	On skin over right patellar tendon





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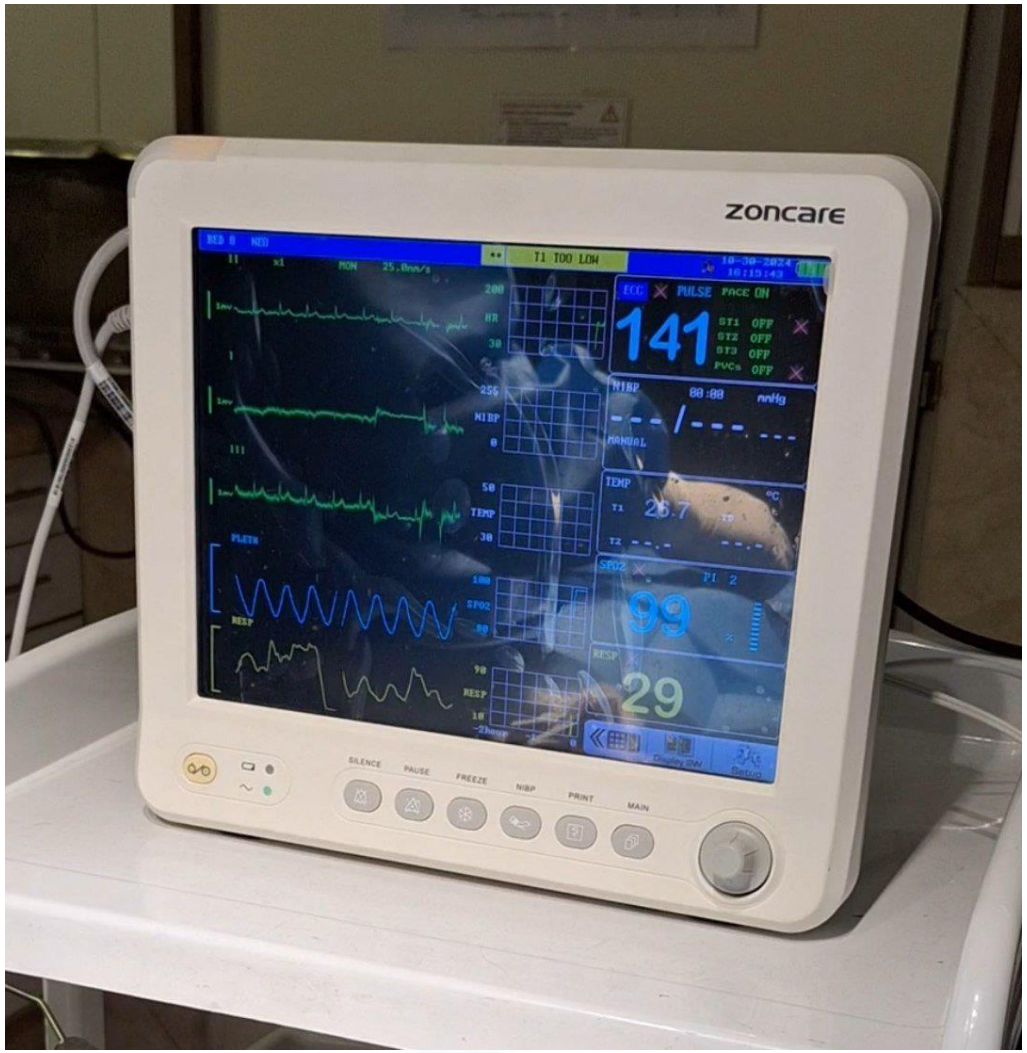
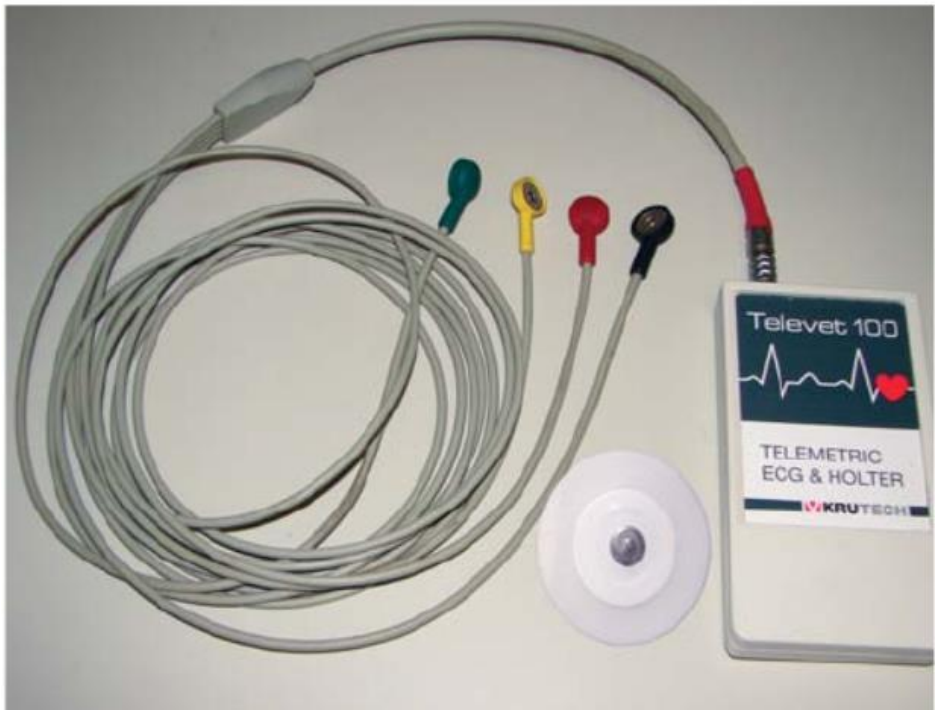


Performing ECG in Horse

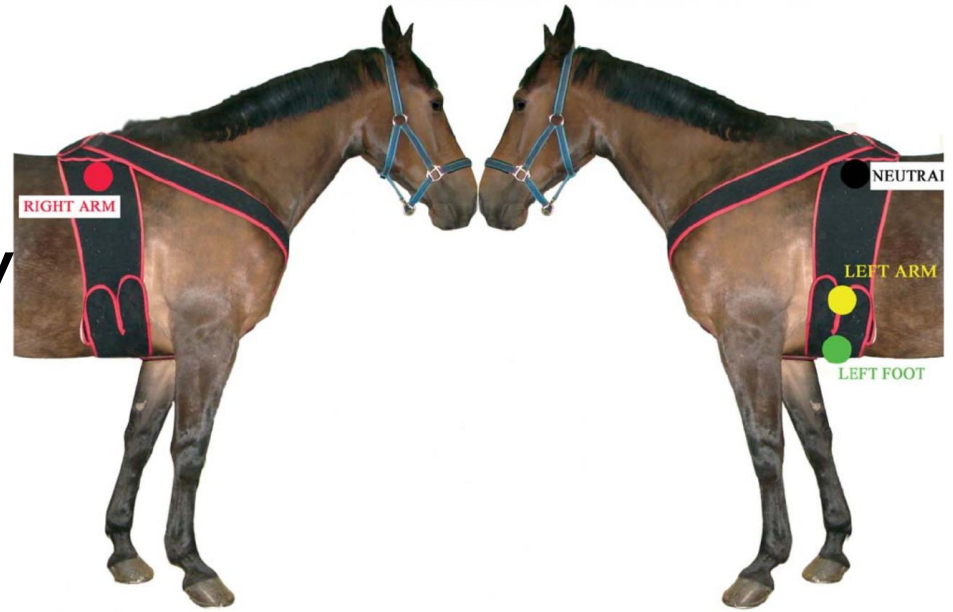
- An ambulatory ECG has high diagnostic value for dysrhythmias that are continuously present. For occasionally occurring dysrhythmias, 24-hour monitoring is necessary.
- Also when a horse is examined for seizures or collapse, continuous ECG monitoring may be necessary to confirm or rule out a cardiac cause.
- To start recording an ECG, electrodes need to be attached to the horse's body and connected to the recording device. Different devices may have 3, 4, or up to10 electrodes.

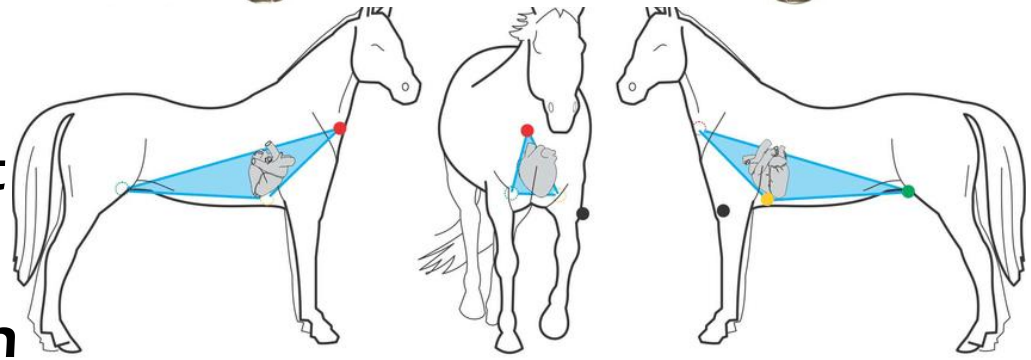


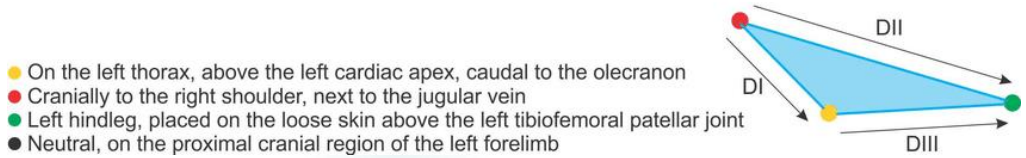
Performing ECG in Horse

III

- There is no universally accepted lead system for the use in large animals
- Systems with 4 electrodes are most commonly used.
  - The black electrode: reference electrode and can be positioned anywhere on the body
  - Lead I between the red (right arm, -) and the yellow (left arm, +) electrode,
  - Lead II between the red (-)and the green (left foot, +) electrode,
  - Lead III be-tween the yellow (-) and the green (+) electrode.



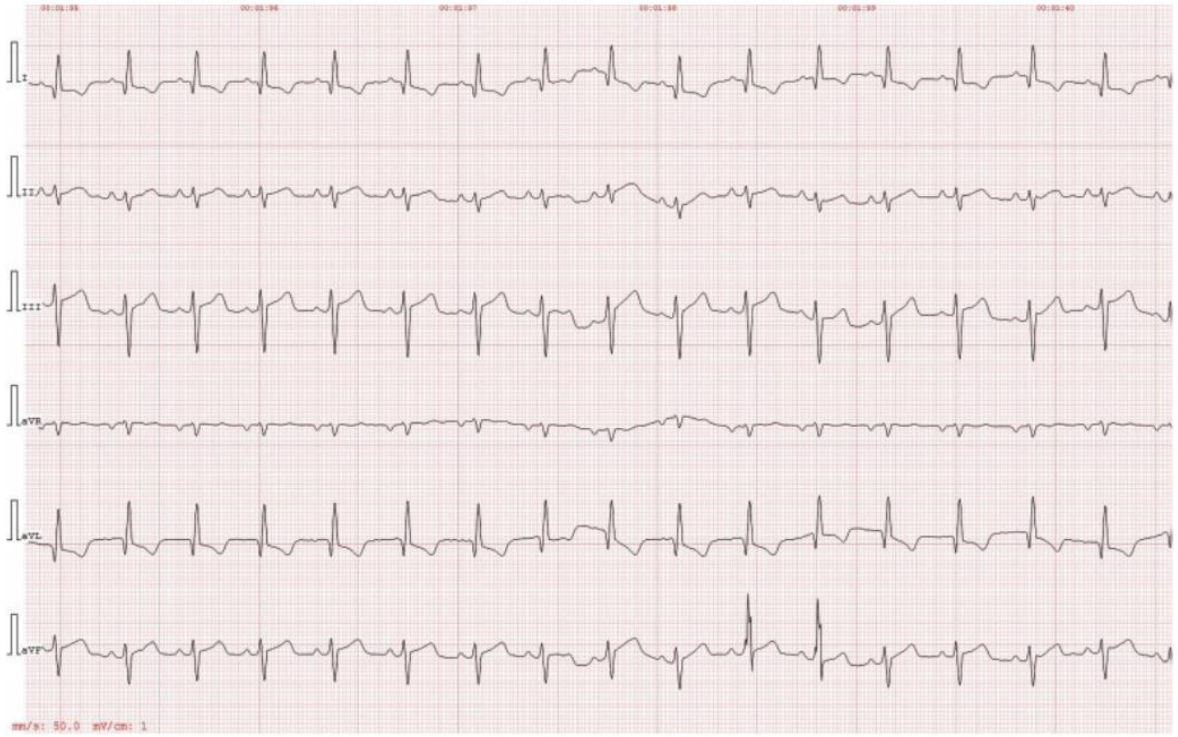




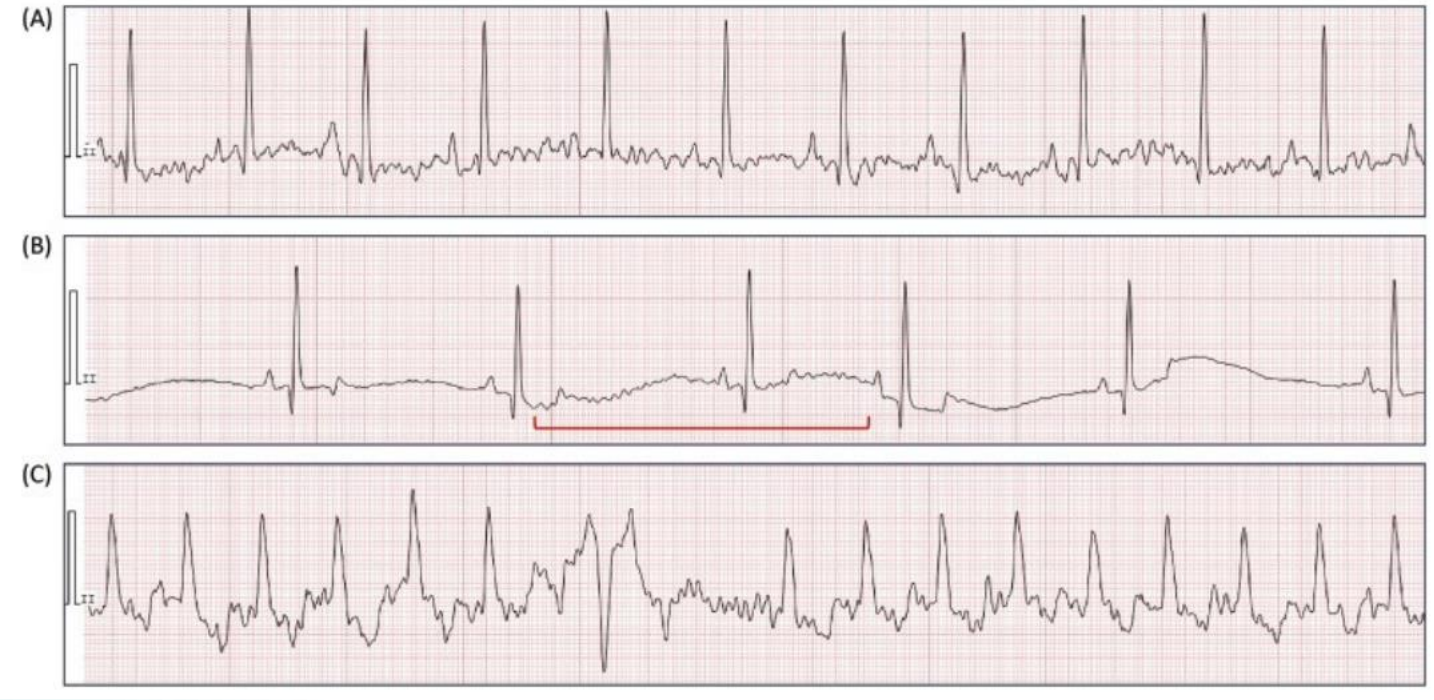
Importance of multiple leads ECG

III

- Issues such as poor electrode contact and also patient conformation will sometimes result in low-complex amplitudes in some of the leads, as illustrated in the trace in this Figure, where leads II and aVR show low-amplitude complexes in comparison to the other leads. In such cases, it may be difficult to distinguish and measure the P, QRS and T waves accurately. If all leads are recorded, then the picture becomes much clearer

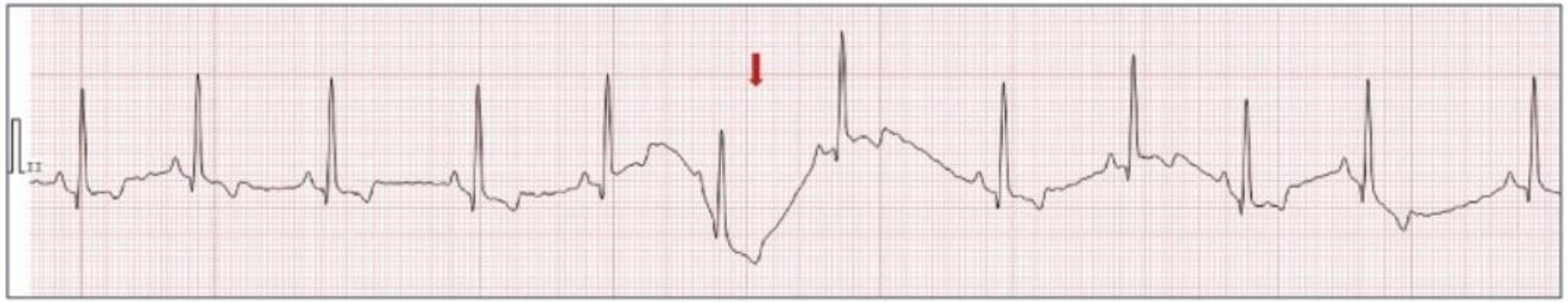


Troubleshooting Common Artefacts

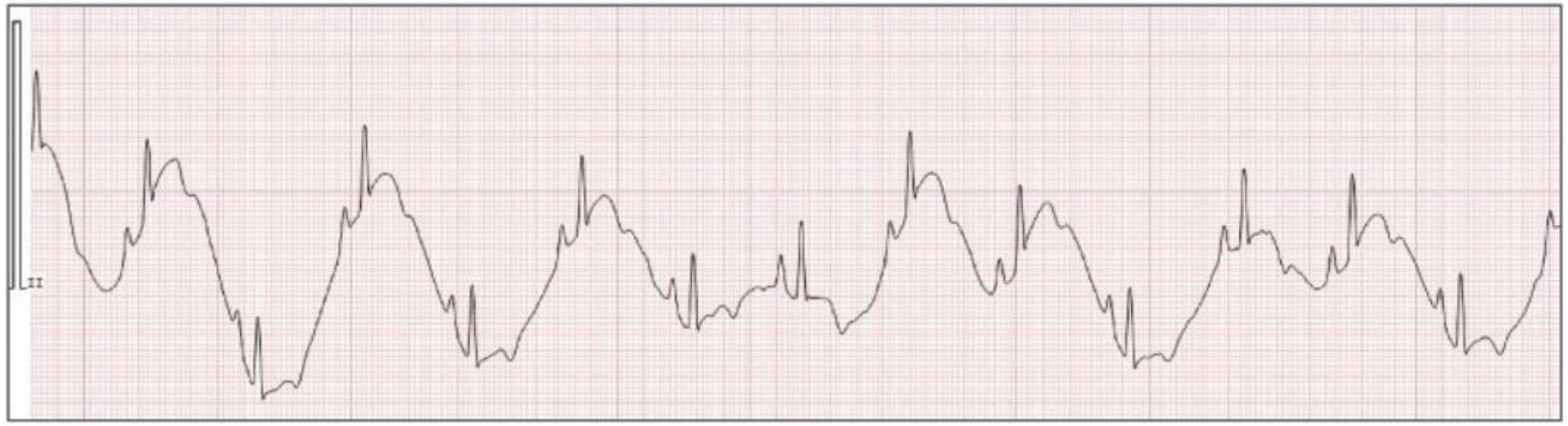


- (A) Muscle tremor. [10-year-old, female neutered, Schnauzer dog] (50mm/s; 20mm/mV)
- (B) Shivering artefact (red bracket). [10-year-old, female neutered, Schnauzer dog] (50mm/s; 20mm/mV)
- (C) Purring artefact. [10-year-old, male neutered, Tonkinese cat] (50mm/s; 20mm/mV)

Troubleshooting Common Artefacts

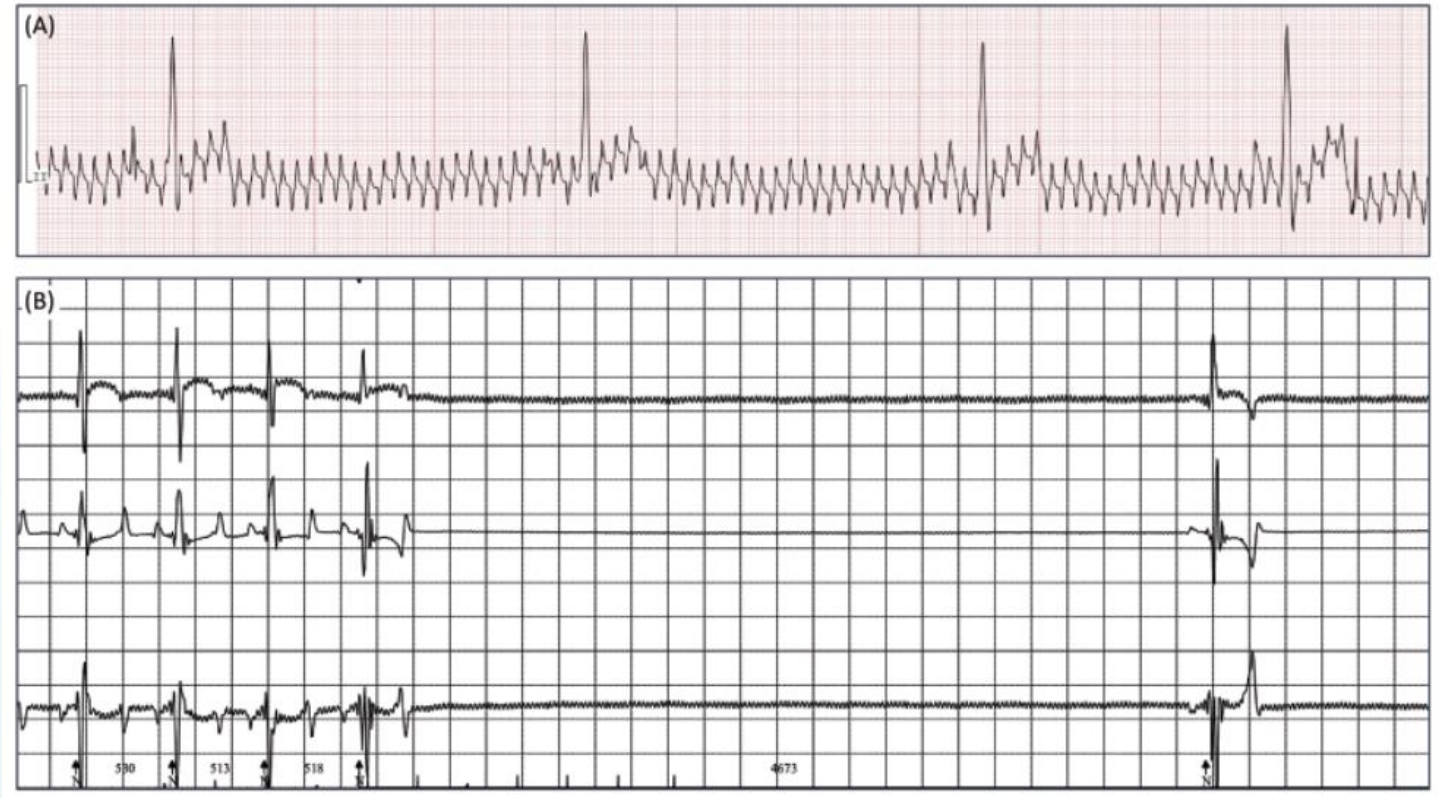


- Movement artefact. A sudden baseline shift is seen (arrow) due to limb movement. [11-year-old, male neutered, West Highland White Terrier dog] (50mm/s; 10mm/mV)



- Breathing movement artefact. Oscillation of the baseline due to breathing movement. [9-year-old, male neutered, Ragdoll cat] (50mm/s; 50mm/mV)

Troubleshooting Common Artefacts

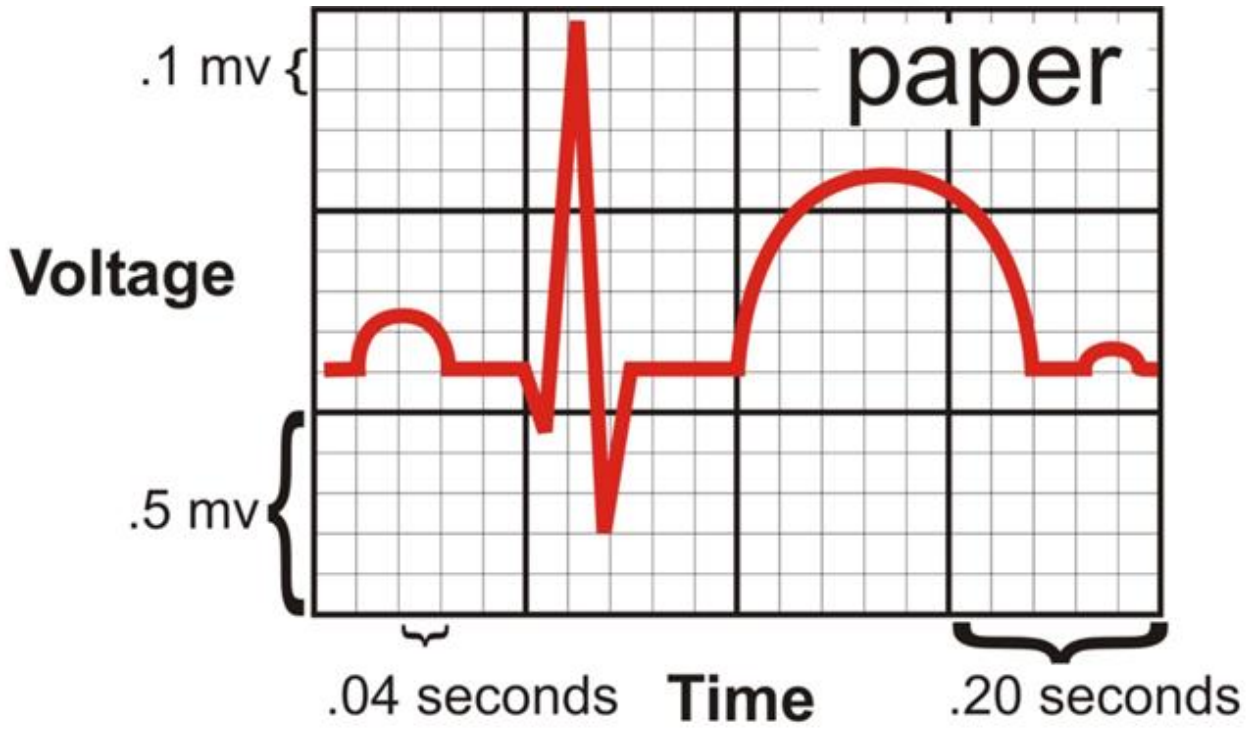


- Electrical interference. Regular, high-frequency, sharp deflections of the baseline may be seen on electrocardiographic (A) and ambulatory ECG (Holter) (B) recordings due to electrical interference. The QRS complexes are visible in all leads, but P waves are not discernible on the electrocardiographic trace (A) and the first channel of the ambulatory ECG (Holter) trace. (A) [8-year-old, female neutered, Hungarian Vizsla dog] (50mm/s; 20mm/mV) (B) [2-year-old, male Lurcher dog

ECG Paper

Paper speed (mm/s)	1 mm in seconds	1 mm in milliseconds
5	0.2	200
25	0.04	40
50	0.02	20

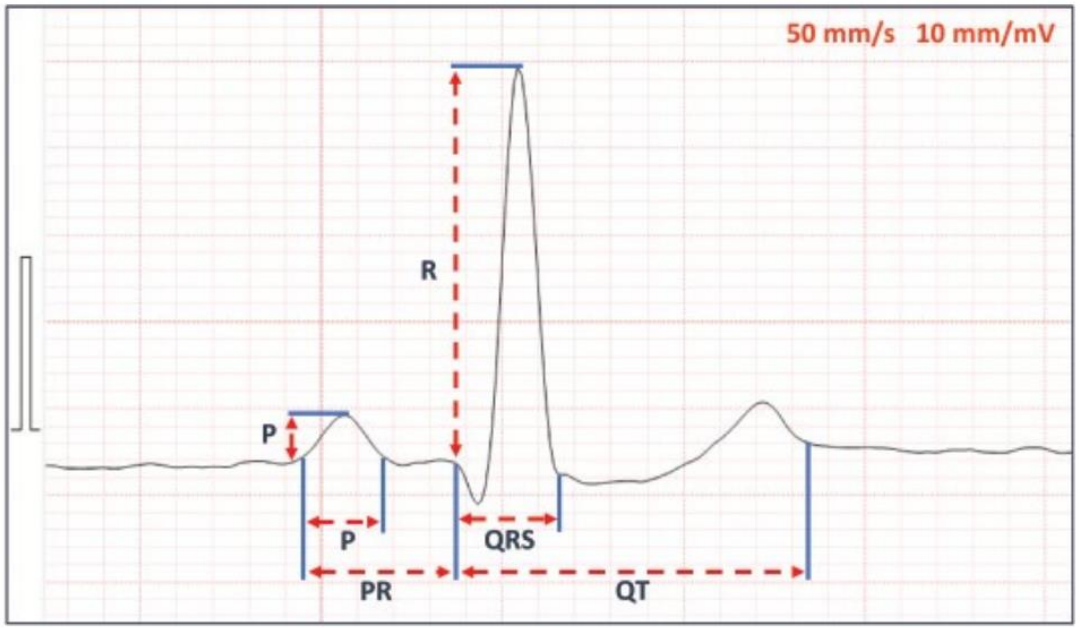
Paper speed (mm/s)	3 seconds	6 seconds
5	1.5 cm	3 cm
25	7.5 cm	15 cm
50	15 cm	30 cm



Paper speed = 25mm / second

ECG Contents

- Measurements of the ECG complex are usually made from lead II, with the paper speed set at 50 mm/s and with the patient in right lateral recumbency.
- The amplitude is recorded in millivolts, and measurements of upward deflections are made from the upper edge of the baseline to the peak of the wave. For downward deflections, measurements are taken from the lower side of the baseline to the lowest point of the wave. The duration of a wave or segment of the complex is taken from start to finish.
- Measurements of duration are not influenced by patient



Applications of ECG

- Acute onset of dyspnea
- Shock
- Fainting or seizures
- Monitoring during and after surgery (monitors depth of anesthesia as well as cardiac monitoring).
- All cardiac murmurs
- Cardiomegaly that is found on thoracic radiographs
- Preoperatively
- Cyanosis
- Evaluating effect of cardiac drugs
- Periocardiocentesis
- Systemic diseases
- Electrolyte disturbances

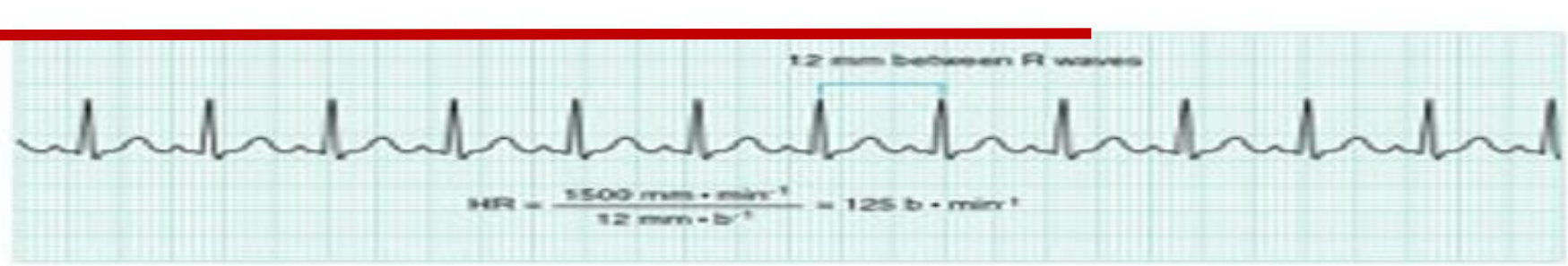
Interpretation of ECG

III

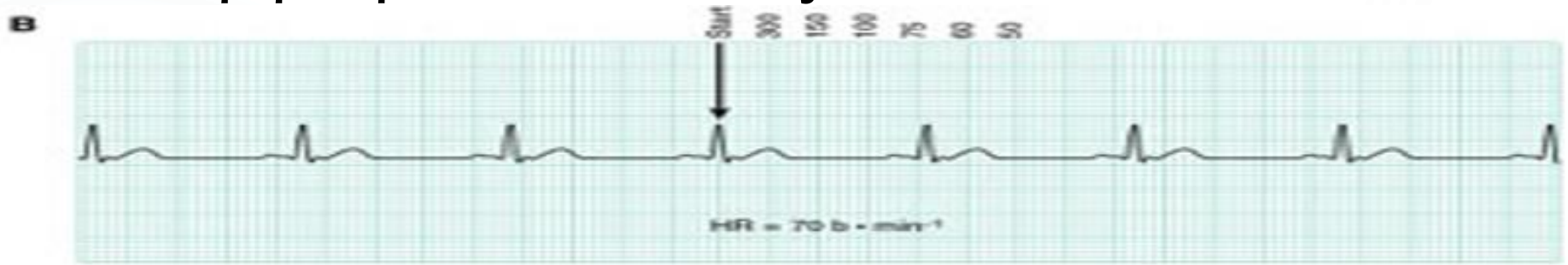
Systematic approach

- Rate
- Rhythm
- Axis
- Wave Morphology
  - P, T, and U waves and QRS complex
- Intervals
  - PR, QRS, QT
- ST Segment

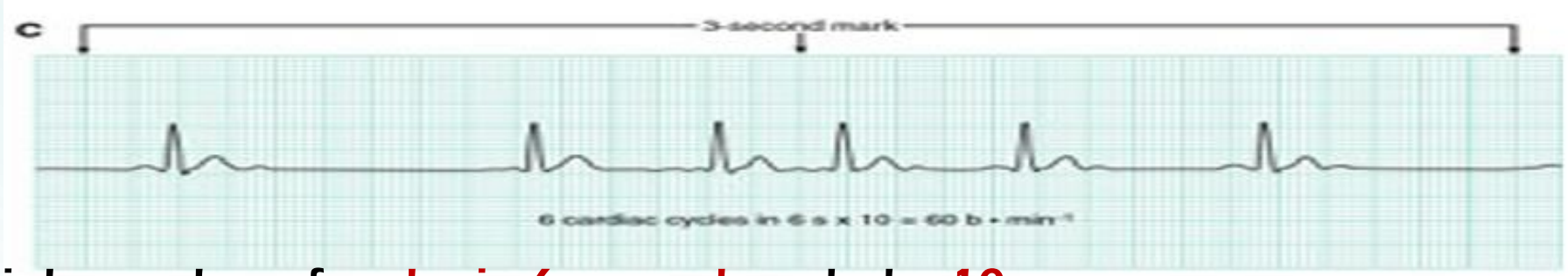
Rate Determination



- At standard paper speed, divide 1500 by distance between R to R waves.



- Find R wave on heavy line. Count off 300, 150, 100, 75, 60 for each following line. Where next R lands is quick estimate.



- Multiply number of cycles in 6 second marks by 10.

Normal Sinus Rhythm

- Normal heart rate:
  - Dogs: <140 bpm
  - Cats: <200 bpm
- P wave in lead II should be upright
- There should be a P wave for every QRS and a QRS wave for every P wave.
- All the beats should be consistently and reasonably related
- P-R intervals should be within the normal limits
- No wide and bizarre beats should be detected and QRS complexes should be narrow.

Normal Sinus Rhythm

III

- This family of heart rhythms all originate from the sinoatrial node and, assuming that the rate is appropriate, represent the normal heart rhythms of dogs and cats.
- The key features of sinus rhythms are:
  - A normal P wave originating from the sinus node in the roof of the right atrium
  - Consistent coupling between the P wave and the ensuing QRS complex
  - Generally, the QRS complexes are narrow and upright in leads II, III and aVF. The exception to this would be if there is aberrant intraventricular conduction which results in a wide-QRS complex.

Parameter	Dog	Cat
Sinus rhythm	Adult: 70–160 bpm Puppy: 70–200 bpm	Adult: 140–220 bpm
Sinus bradycardia	Adult: <60 bpm Puppy: <70 bpm	<100–120 bpm
Sinus tachycardia	Adult: >180 bpm Puppy: >200 bpm	>220 bpm

Note: As heart rate is a highly labile parameter, it is understandable that wide fluctuations are possible in normal individuals, and therefore the numbers quoted should be used only as a guide rather than interpreted rigidly.
Source: Data from Tilley (1995).[1]

Normal Sinus Rhythm

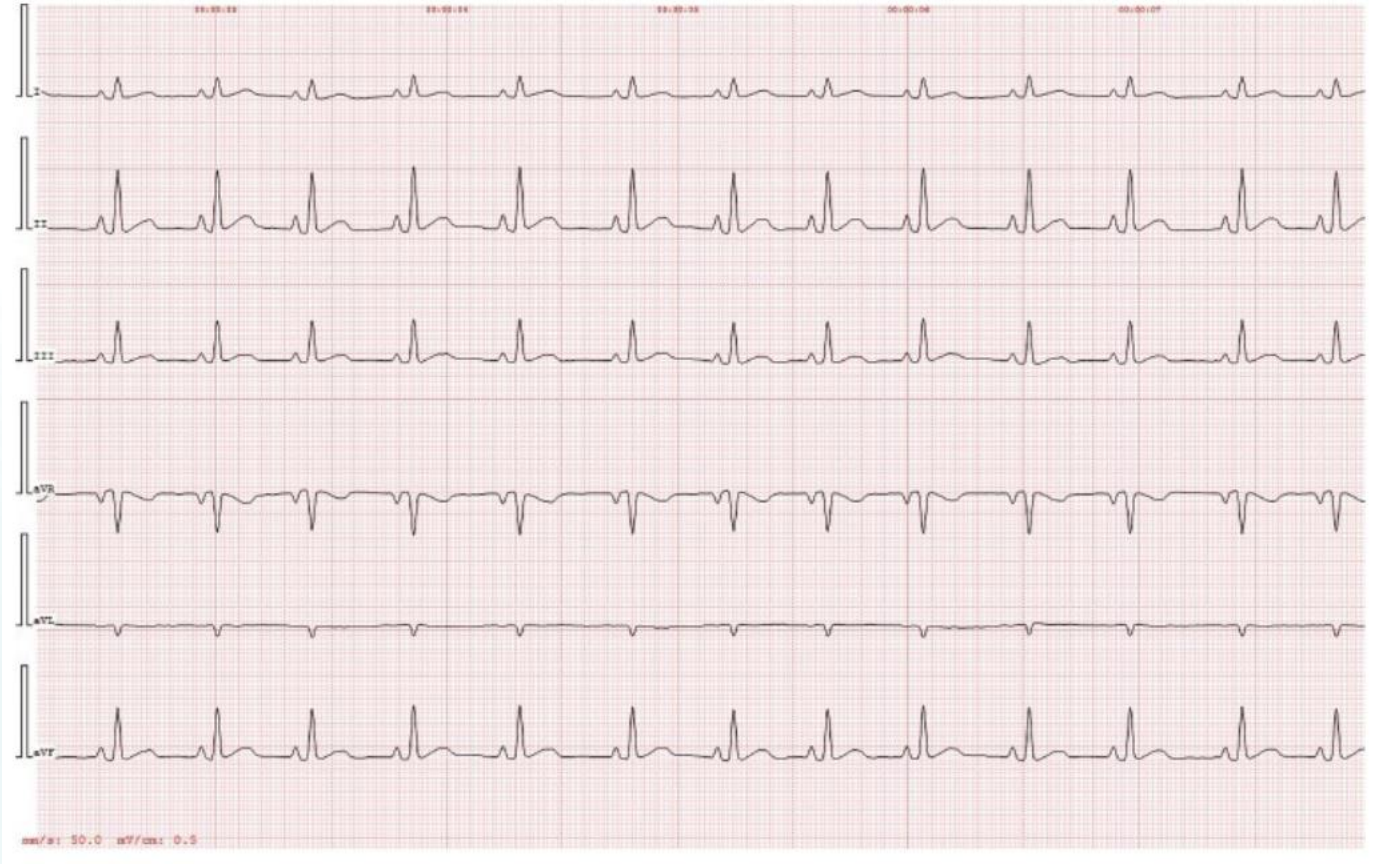
III

- **Sinus rhythm** is a normal heart rhythm seen in cats and dogs.
- The distinction between sinus rhythm, **sinus bradycardia** and **sinus tachycardia** depends on the heart rate
- Sinus rhythms originate from the sinoatrial node located in the roof of the right atrium.

Rate	*Dog*: A rate appropriate for temperament and level of activity, usually around 120 bpm *Cat*: A rate appropriate for temperament and level of activity, usually around 150 bpm
Regularity	Regular
Onset/ offset	Changes in heart rate are gradual.
P wave	P waves are present and positive in leads II, III and aVF; they are negative in aVL and aVR, with an electrical axis suggesting that the origin is in the roof of the right atrium (+18° to +90° in dogs, 0 to +90° in cats).
P:QRS ratio	P:QRS is 1:1 with consistent coupling and normal duration unless there is atrioventricular block.
QRS	A QRS is present after each P wave with a normal appearance (R wave in leads II, III and aVF; S wave in leads aVL and aVR) and duration <70 ms in dog, and <40ms in cat, indicating normal intraventricular conduction and activation.

Normal Sinus Rhythm

III

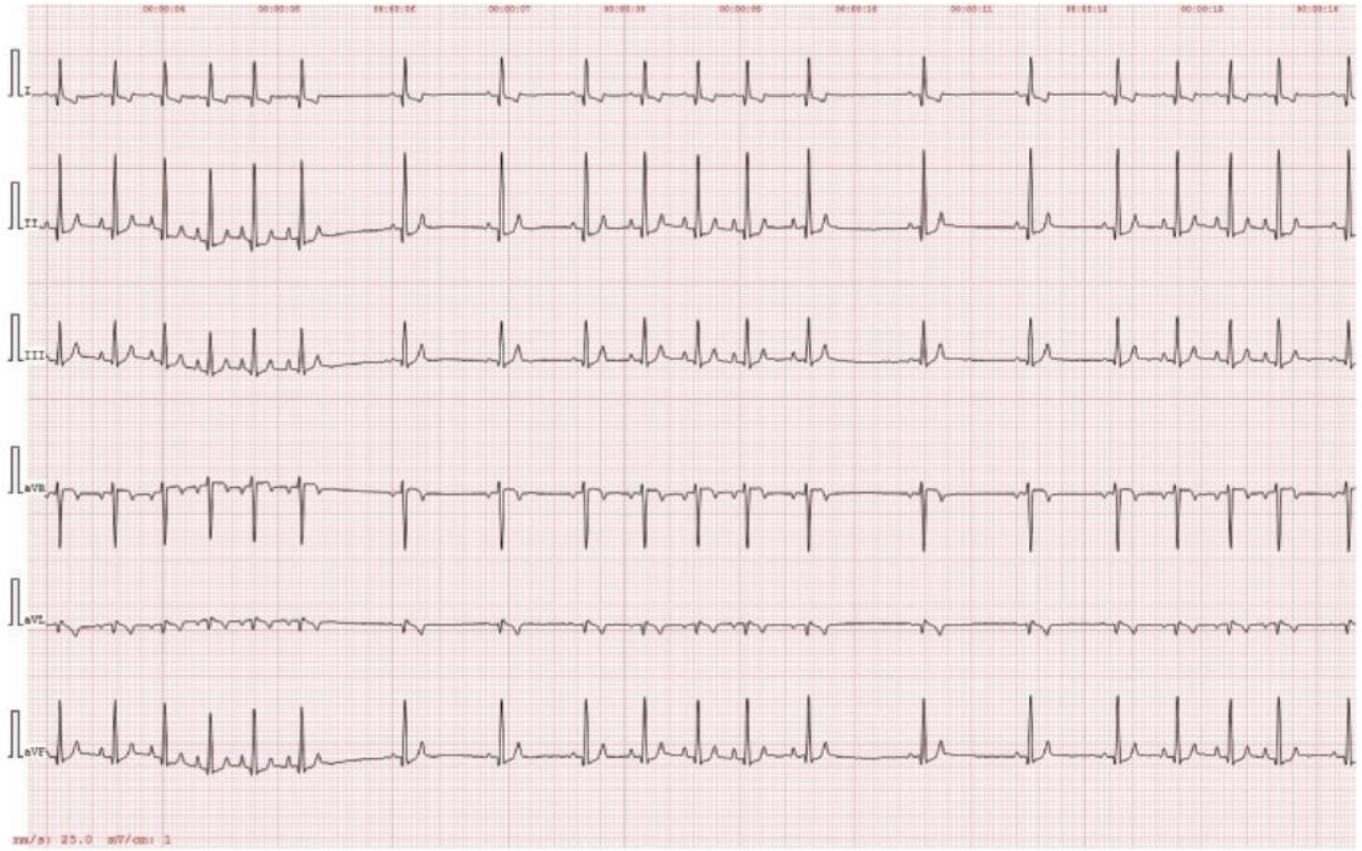


Six-lead electrocardiogram during sinus rhythm in a cat. A normal (sinus) P wave is seen in all beats with an electrical axis of approximately 65°, consistent with an origin in the roof of the right atrium (0 to +90°; positive wave in leads II, III and aVF; negative wave in leads aVL and aVR)

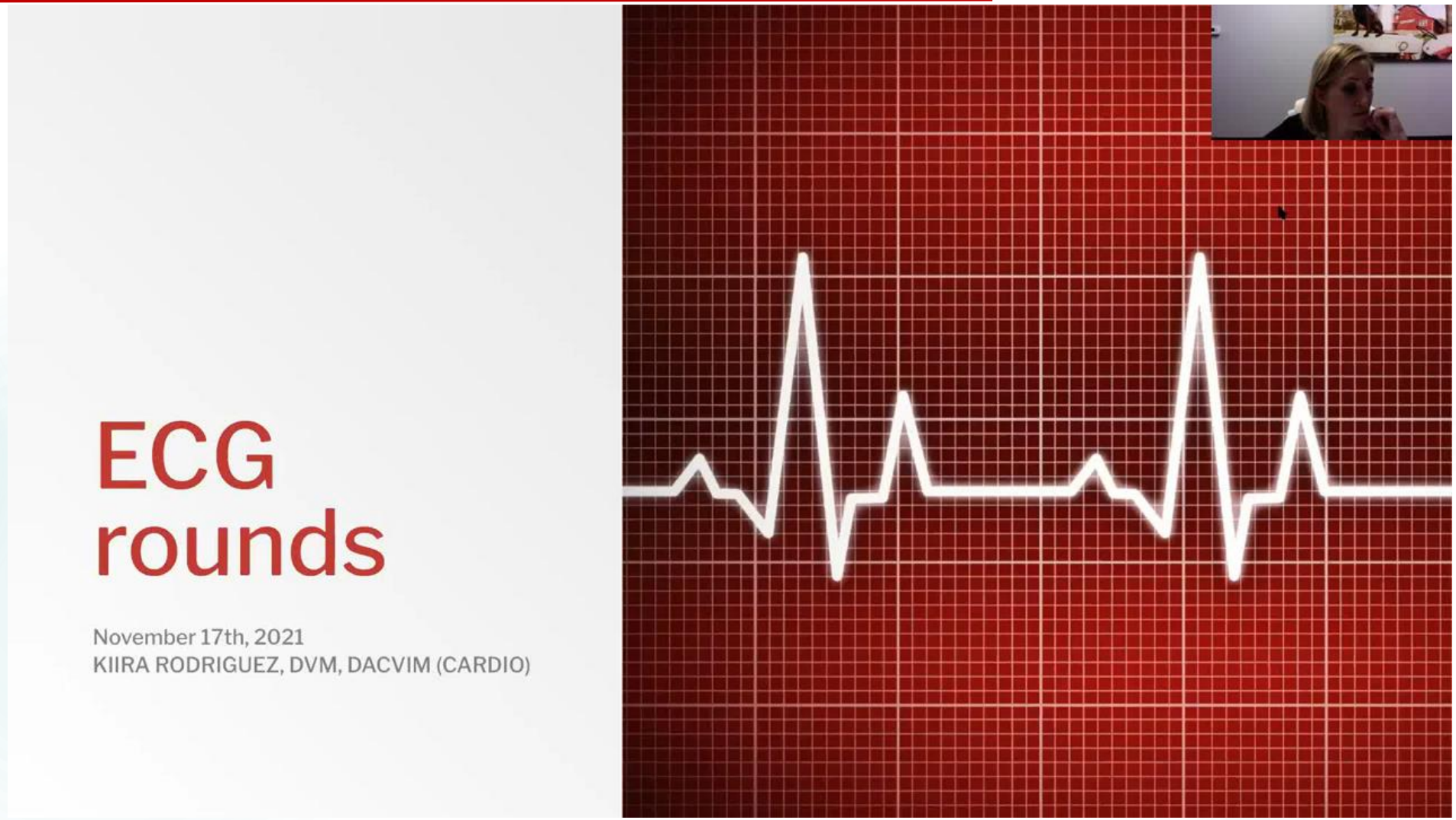
Sinus Arrhythmia

III

- Sinus arrhythmia is a regularly irregular rhythm commonly seen in normal dogs, especially in the brachycephalic breeds, and it describes a rhythmic variation in heart rate.
- During sinus arrhythmia, the R-R interval shortens with inspiration and lengthens with expiration, and this is a well-recognised feature of healthy heart function.



Normal Sinus Rhythm



- **Form 11:10 to 13:30**

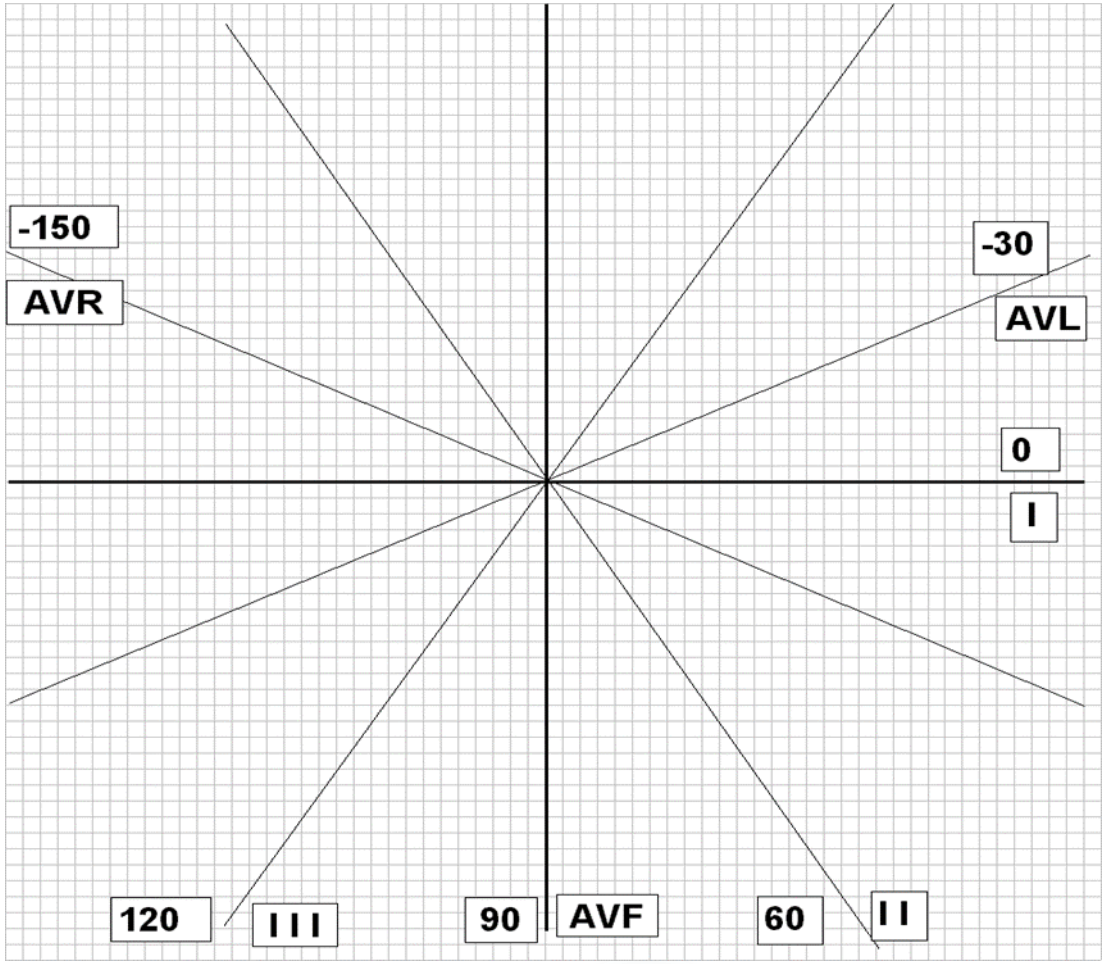
Mean Electrical Axis

III

- The electrical axis of the heart is the total sum of the many electrical vectors generated by the action potentials of individual ventricular myocyte.
- The ventricular electrical axis, sometimes also known as the MEA, is the average direction of ventricular depolarisation during the whole of the QRS, and this may be clinically relevant in cases where we suspect abnormal conduction through the ventricles – for example, due to an area of the conduction system being diseased or blocked.
- The electrical axis can also be useful when evaluating some supraventricular tachycardias, especially those with an abnormal pathway connecting the atria and ventricles, as this pathway changes how the ventricle depolarises.

Hexaxial Array for Axis Determination

- Determination of the angle of the main cardiac vector in the frontal plain using 2 examples:

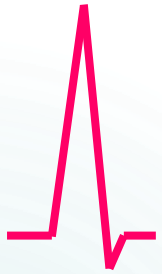


Hexaxial Array for Axis Determination

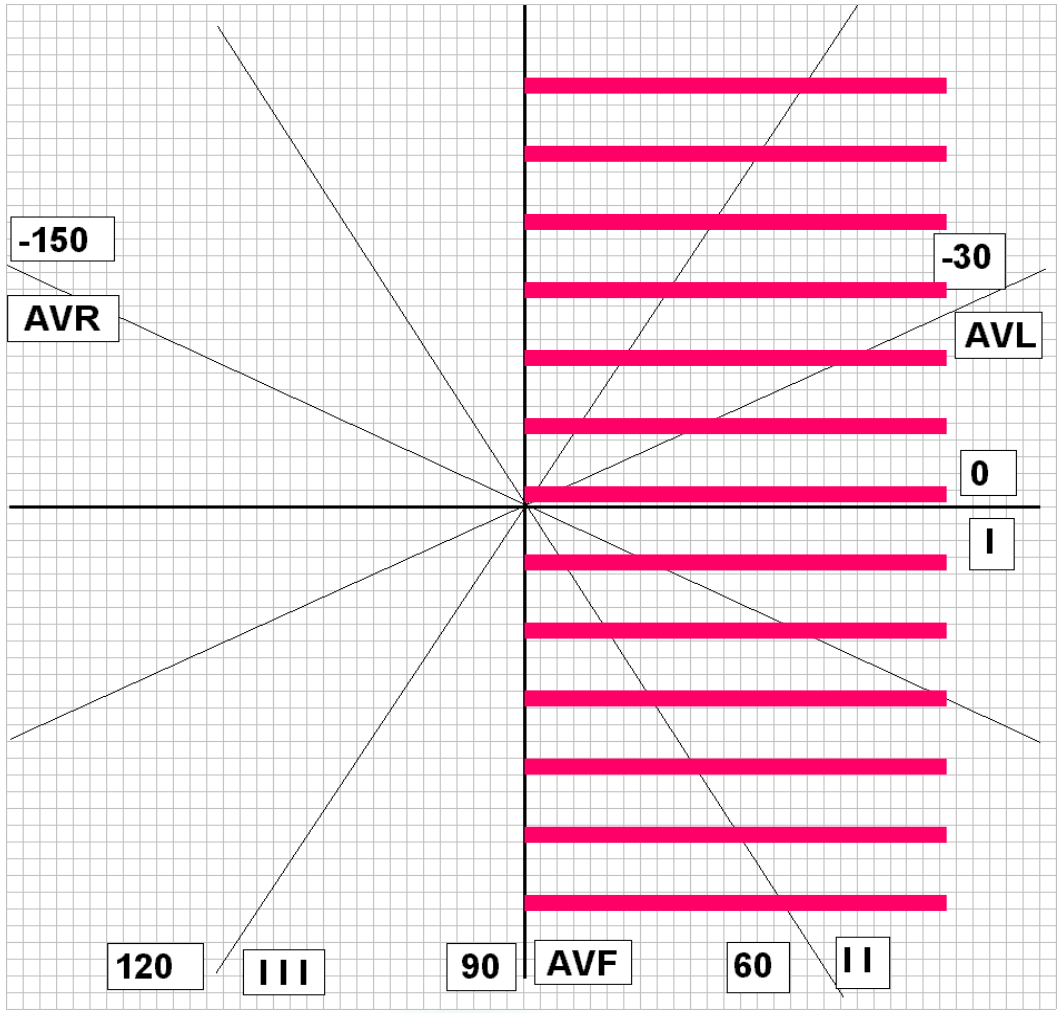
III

- Example 1:

Lead I:



- If lead I is mostly positive, theaxis must lie in the right half ofof the coordinate system (the main vector is moving mostly toward the lead's positive electrode)

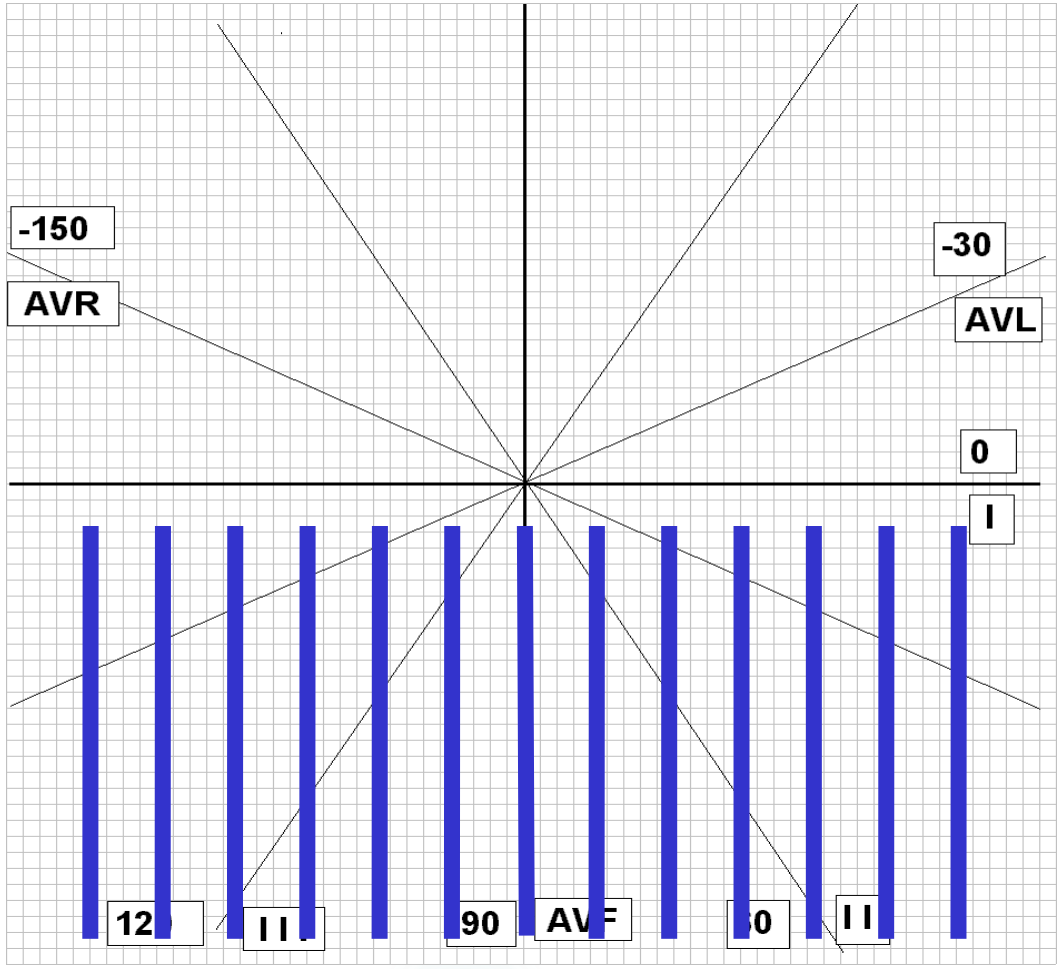


Hexaxial Array for Axis Determination

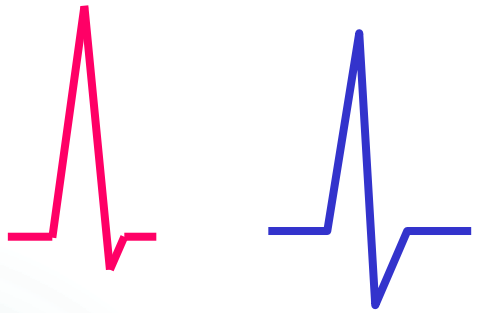
III

Lead aVF

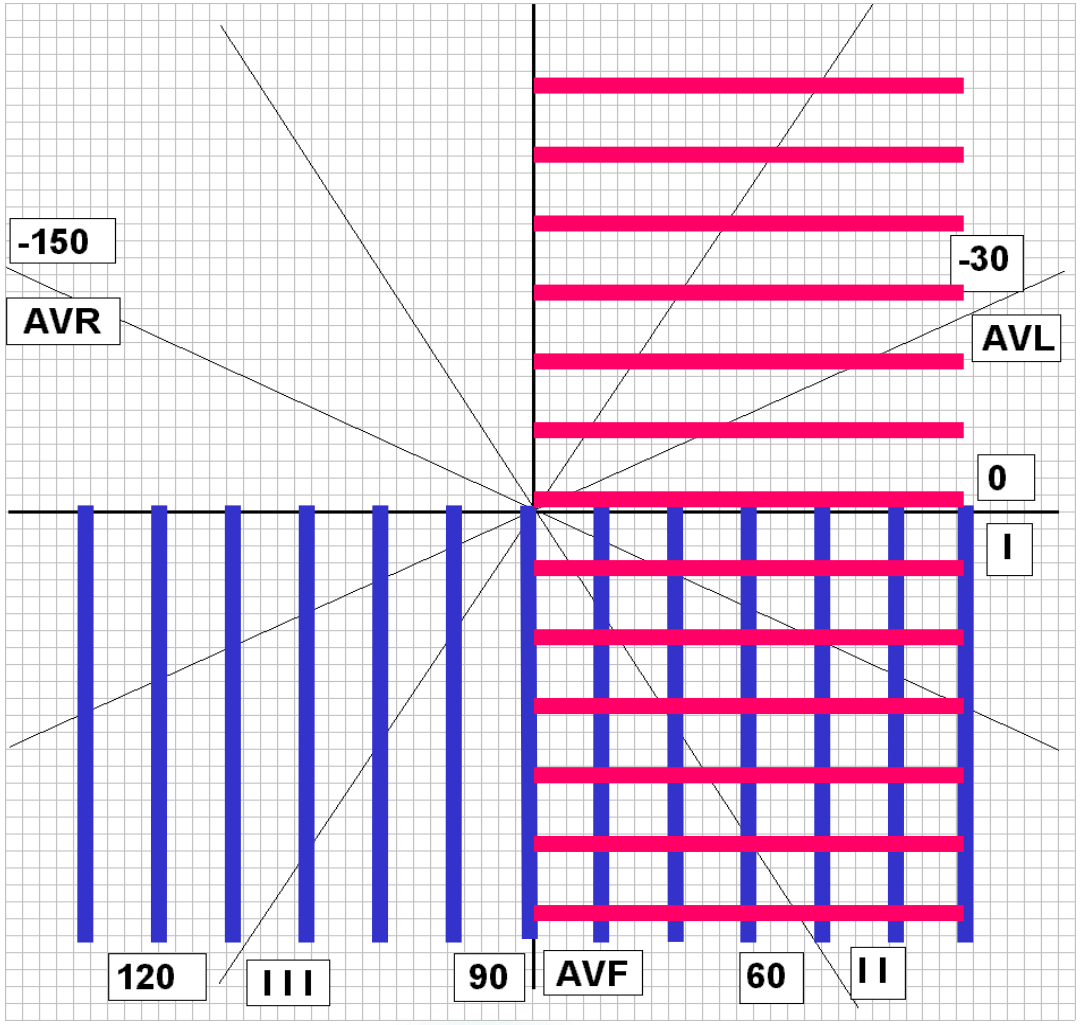
- If lead aVF is mostly positive, the axis must lie in the bottom half of the coordinate system (again, the main vector is moving mostly toward the lead's positive electrode



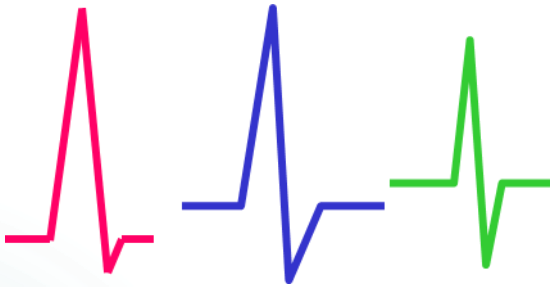
Hexaxial Array for Axis Determination



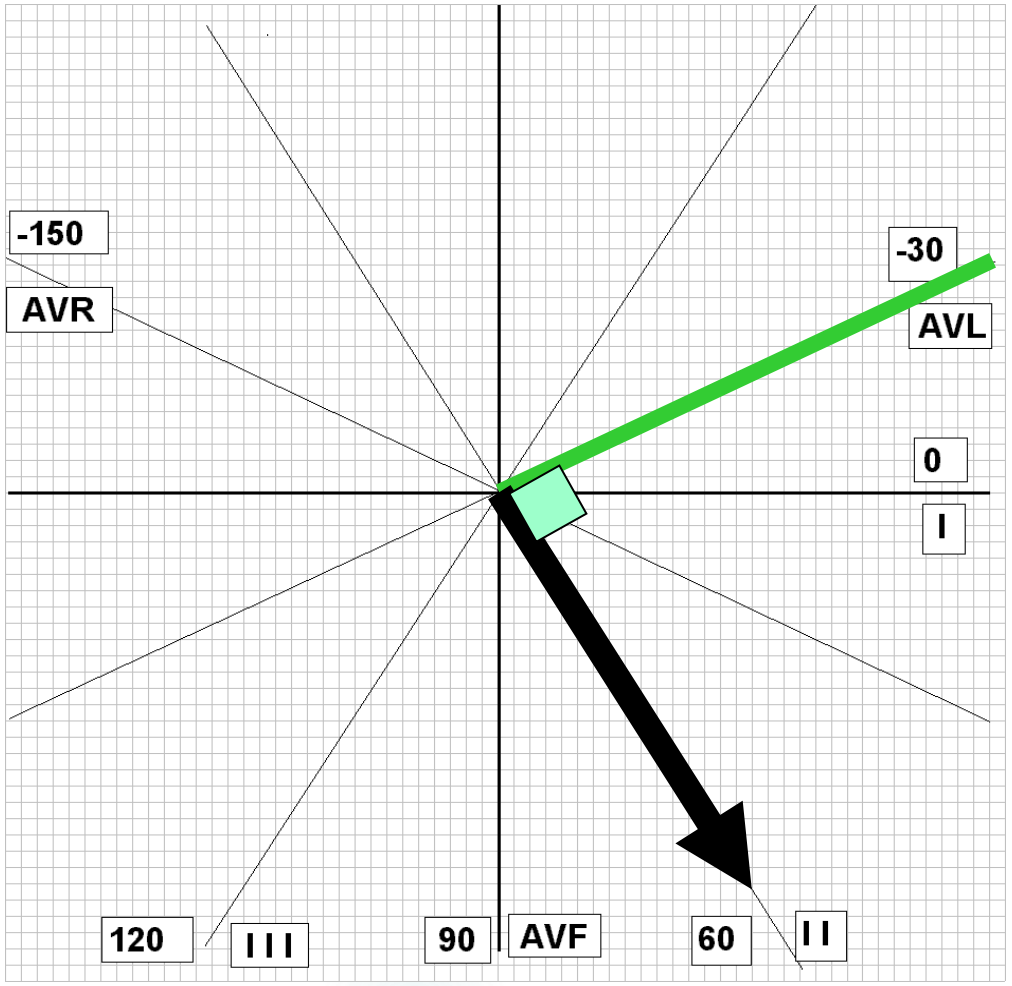
- Combining the two plots, we see that the axis must lie in the bottom right hand quadrant



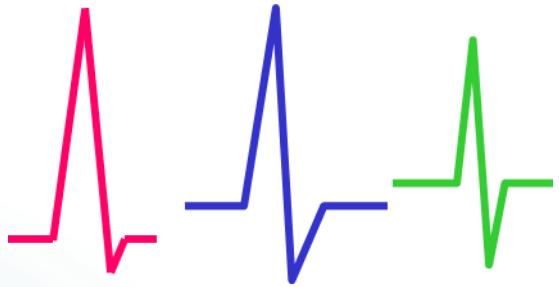
III



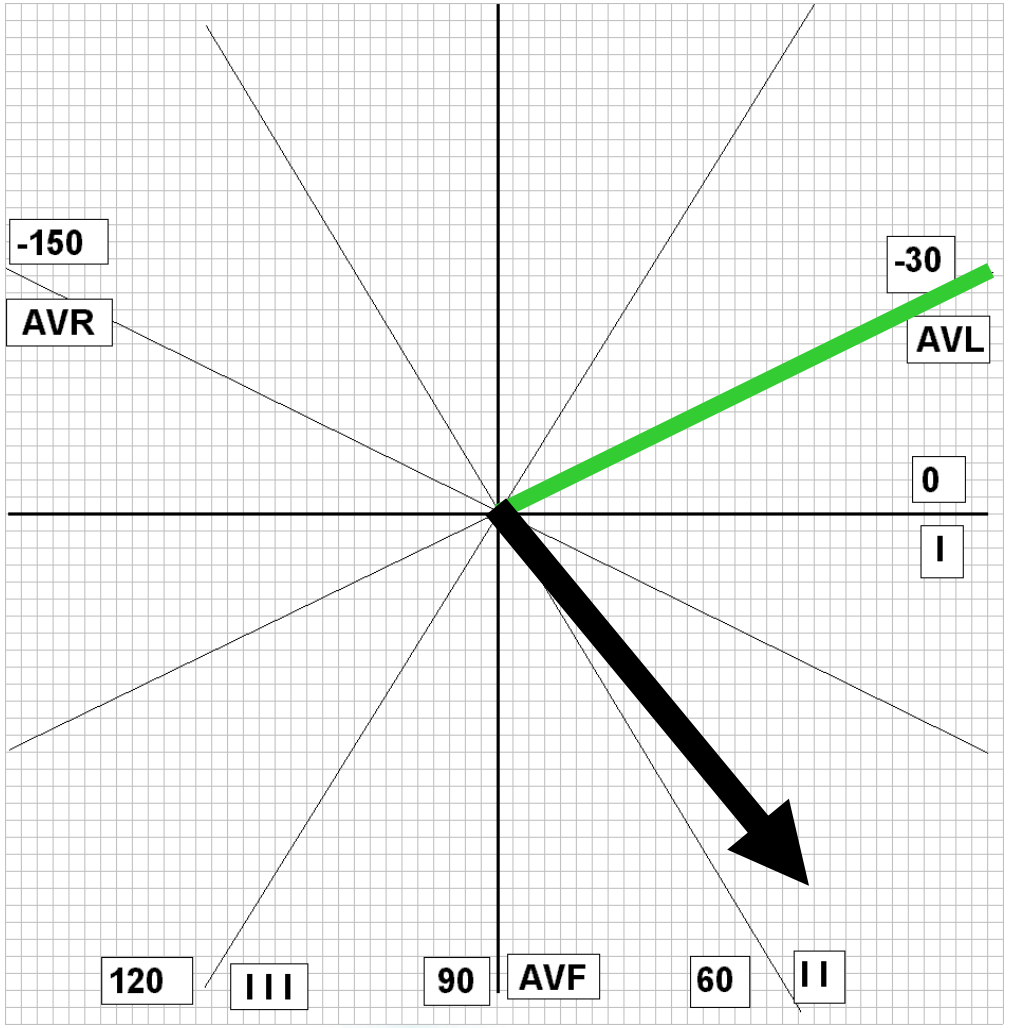
- Once the quadrant has been determined, find the most equiphasic or smallest limb lead. The axis will lie about 90° away from this lead. Given that aVL is the most equiphasic lead, the axis here is at approximately 60°.



Hexaxial Array for Axis Determination



- Since QRS complex in aVL is a slightly more positive, the true axis will lie a little closer to aVL (the depolarization vector is moving a little more towards aVL than away from it). A better estimate would be about 50o (normal axis).



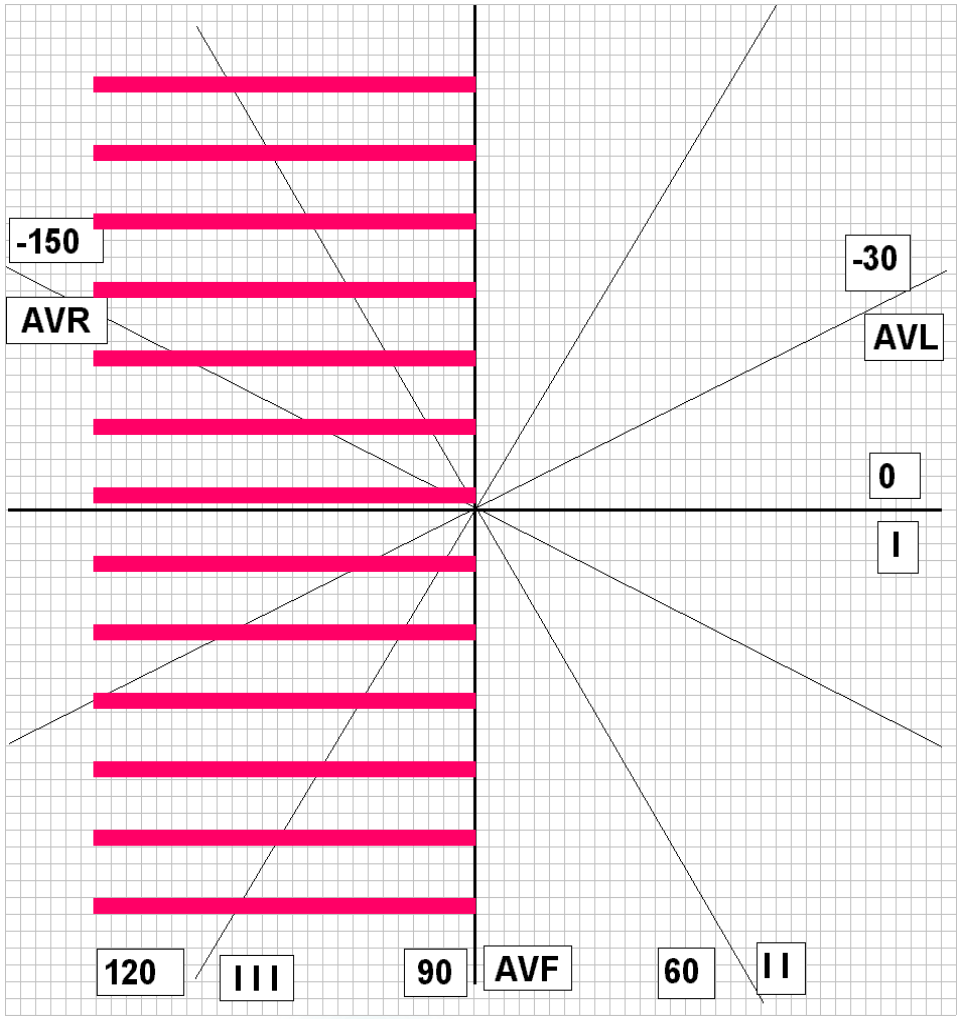
Hexaxial Array for Axis Determination

III

- Example 2:

Lead I

- If lead I is mostly negative, the axis must lie in the left half of of the coordinate system.

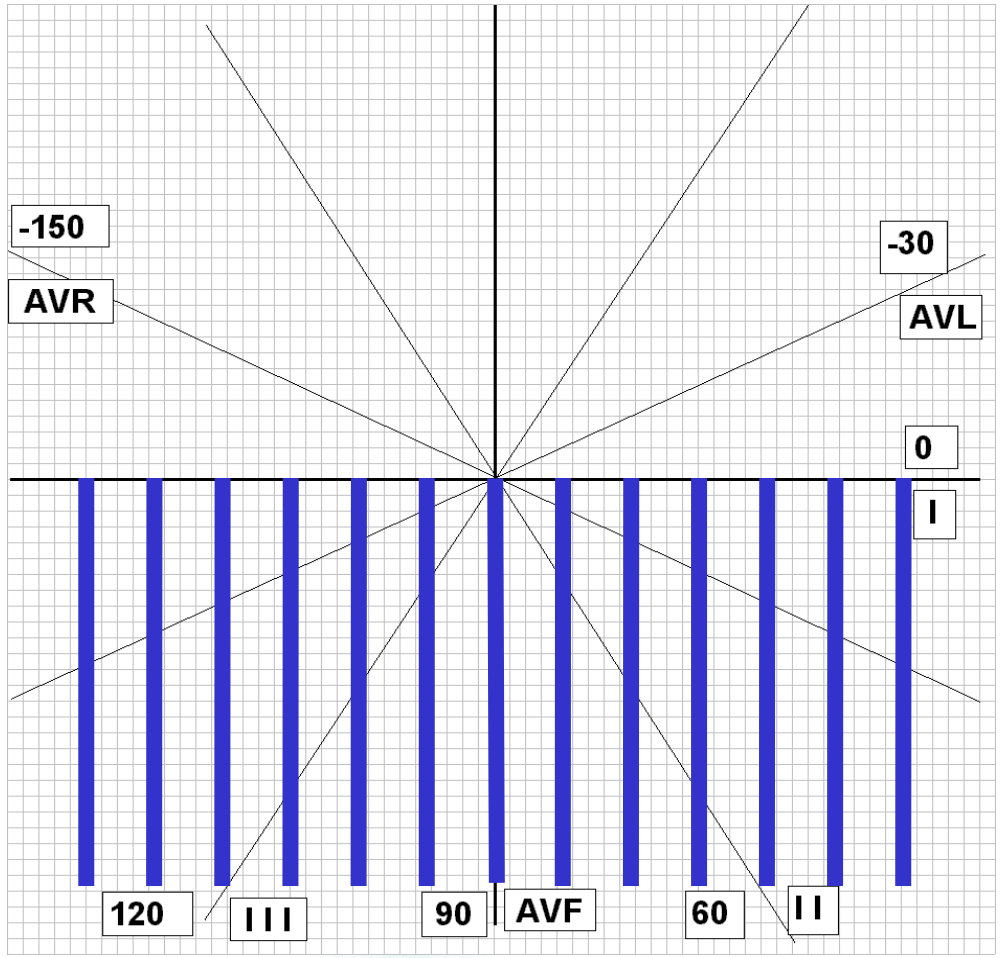


Hexaxial Array for Axis Determination

III

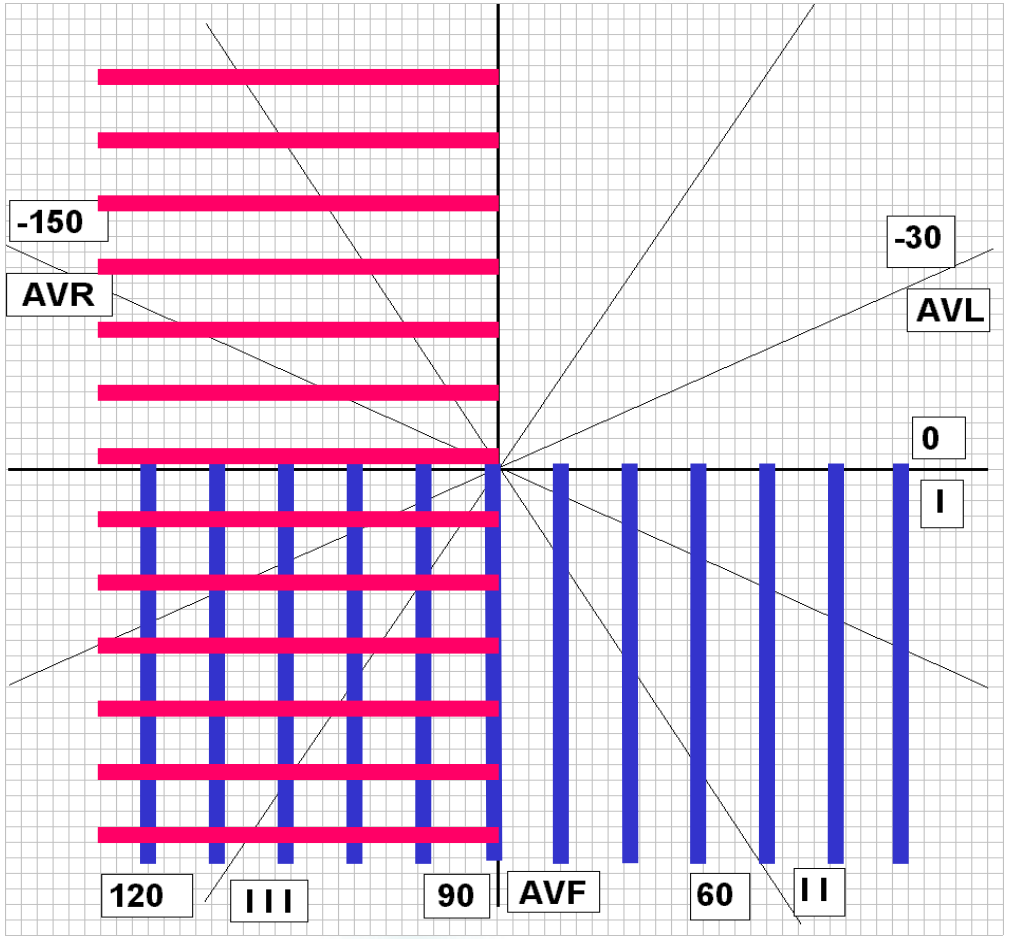
Lead aVF

- If lead aVF is mostly positive, the axis must lie in the bottom half of the coordinate system

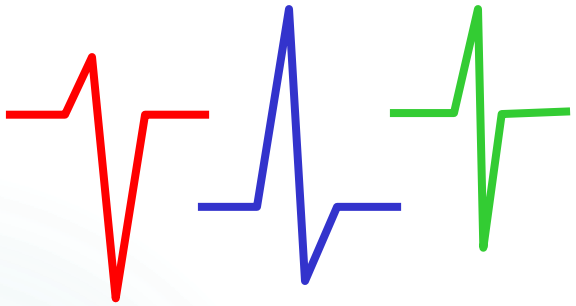


Hexaxial Array for Axis Determination

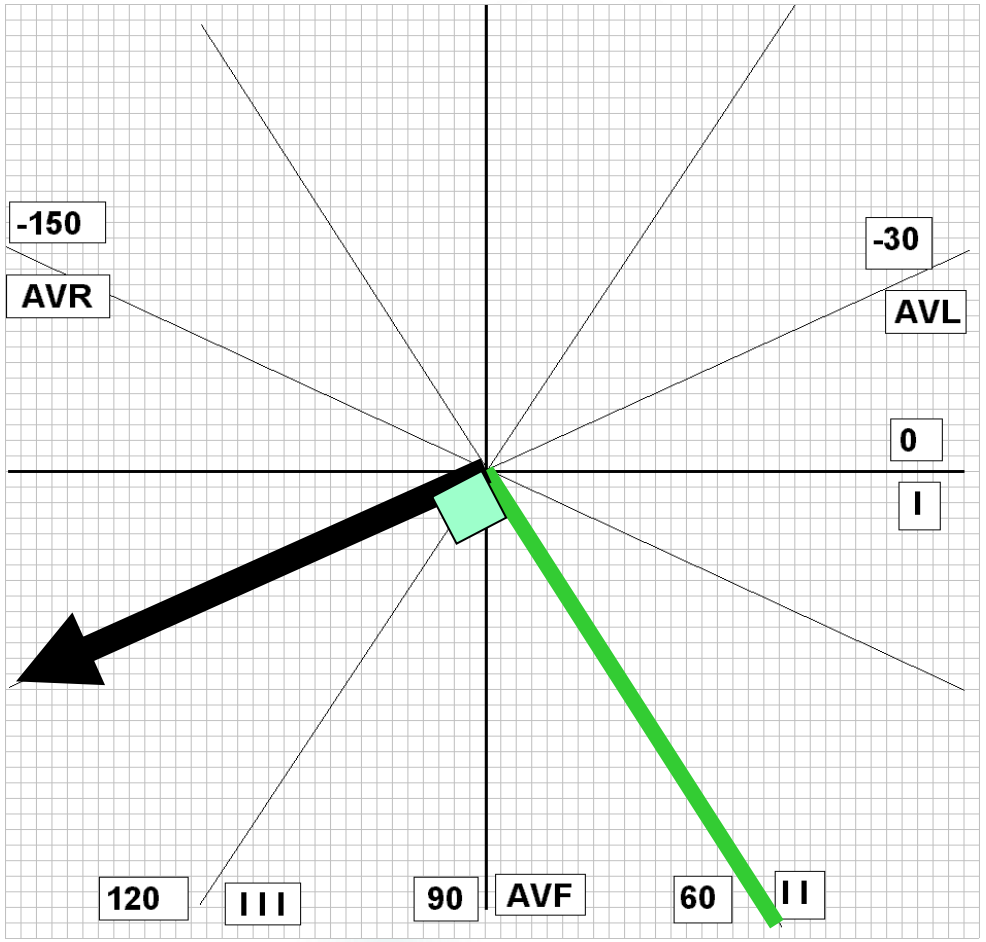
- Combining the two plots, we see that the axis must lie in the bottom left hand quadrant (Right Axis Deviation)



Hexaxial Array for Axis Determination



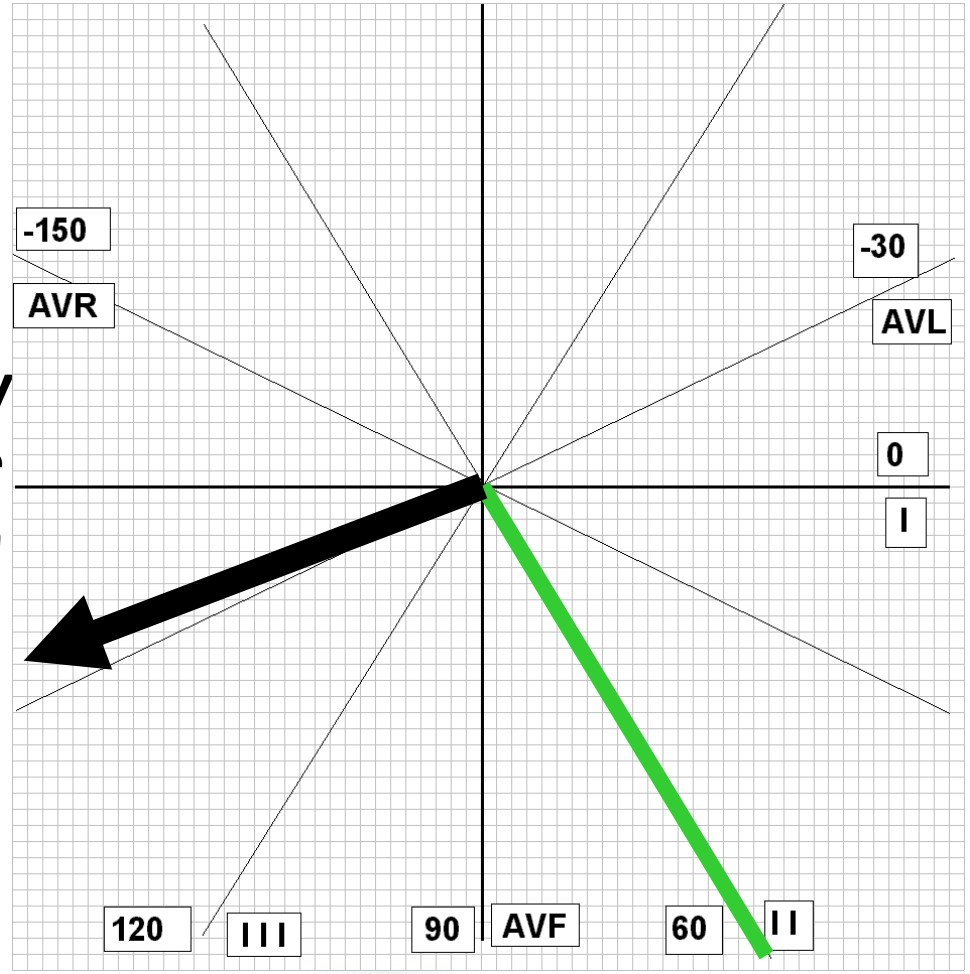
- Once the quadrant has been determined, find the most equiphasic or smallest limb lead. The axis will lie about 90° away from this lead. Given that II is the most equiphasic lead, the axis here is at approximately 150°.



Hexaxial Array for Axis Determination

III

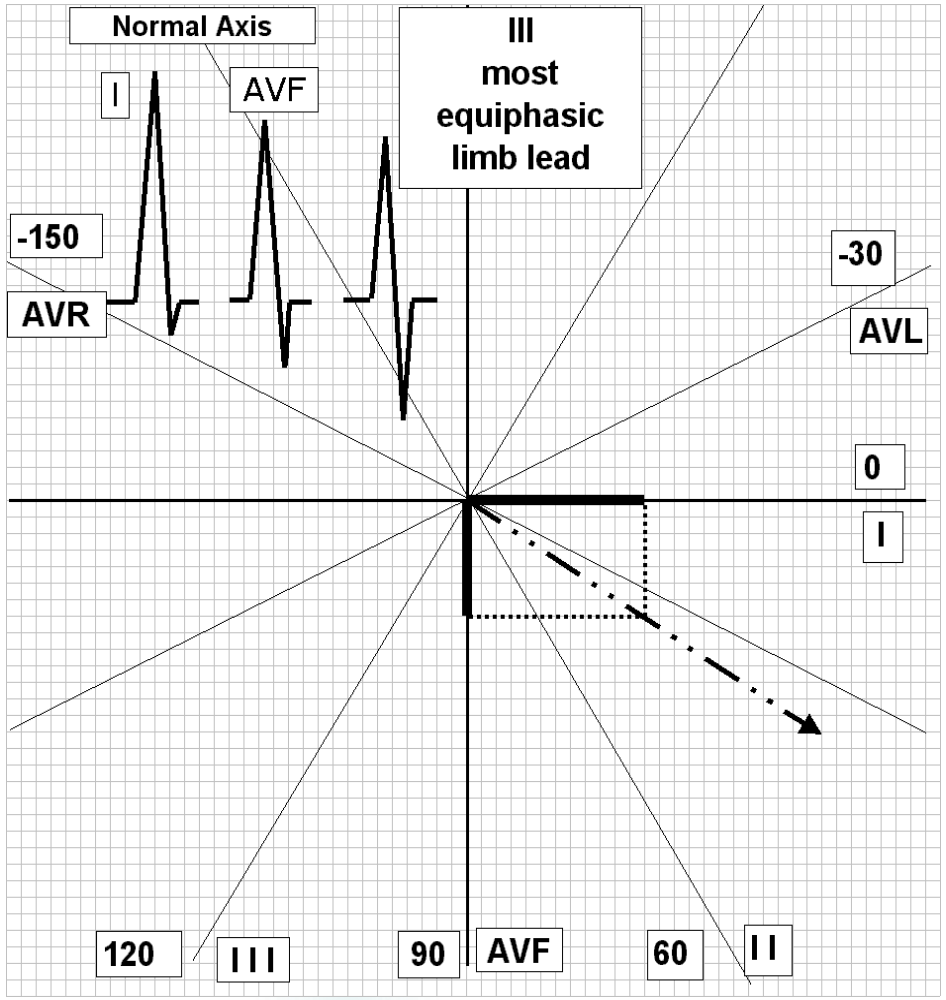
- Since the QRS in II is a slightly more negativ farther away from lead II than just 90o (the moving a little more away from lead II than would be 160o.



Hexaxial Array for Axis Determination

Precise Axis Calculation

- Precise calculation of the axis can be done using the coordinate system to plot net voltages of perpendicular leads, drawing a resultant rectangle, then connecting the origin of the coordinate system with the opposite corner of the rectangle. A protractor can then be used to measure the deflection from 0.



Hexaxial Array for Axis Determination

III

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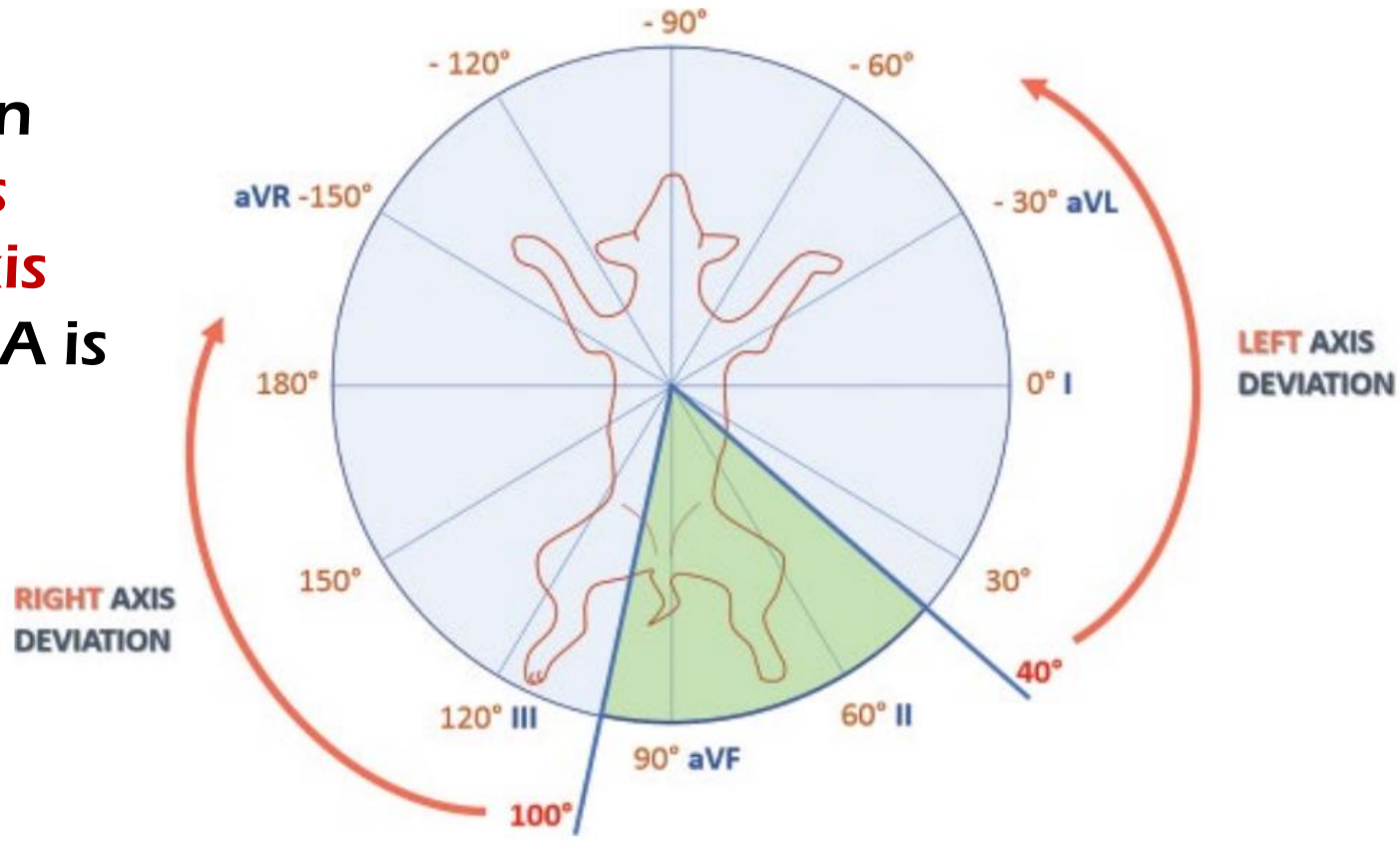
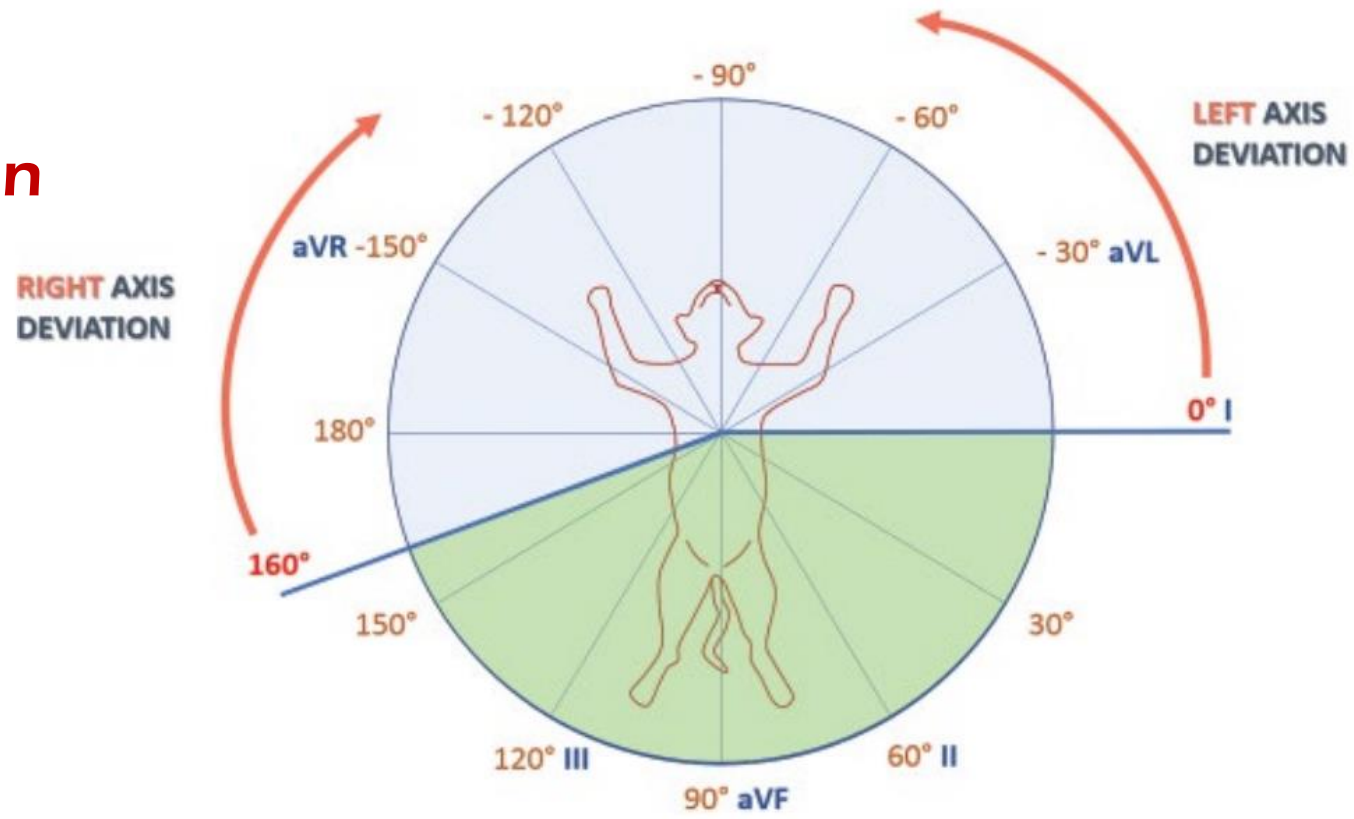
Mean Electrical Axis

- The normal MEA in dogs varies from +40° to +100°.
- Any dog with a MEA less than +40° is said to have a left axis deviation, whereas a right axis deviation is present if the MEA is greater than +100°.



Mean Electrical Axis

- The normal MEA in cats varies from 0° to +160°.
- A MEA less than 0° is said to be deviated to the left, whereas a right axis deviation is present if the MEA is greater than +160°.



Good Luck!