1

The P-QRS-T

Basics

CHAPTER MENU

Leads In the frontal plane, that is, the plane that divides the dorsal portion of the animal from the ventral portion, there are six leads that are used to generate an electrocardiogram (EKG, ECG). These are the leads used to create a mean electrical axis (MEA) for the QRS complex. Leads I, II, and III are the bipolar limb leads, and the augmented (unipolar) leads are aVL, aVR, and aVF. The lead attached to the R rear limb (color-coded green) is simply a ground and can really be placed anywhere on the animal. The electrodes may be attached anywhere on the limb, as long as they are positioned approximately equidistant from the heart. The further the leads are placed toward the paws, the greater the chance of baseline artifact from movement. The augmented leads use two of the other leads as one, with the negative pole intermediate between them. Electrodes are placed at the right (R, color-coded white) and left (L, color-coded black) forelimbs and the left rear limb (LL, color-coded red) to get these leads. Leads II, III, and aVF are termed the "inferior" leads (inferior being analogous to caudal in small animals). Leads I and aVL are termed the left lateral leads. The V leads (precordial leads, the left of which are the only ones used with any frequency) are along the horizontal plane – a human term, which is why it is confusing in small animals (the analogue is the transverse plane) – which divides the cranial portion of the animal from the caudal portion. The point at which the QRS complexes change from a rS to Rs pattern (isoelectric RS wave) in the precordial leads is known as the transition zone (normally in V3 or V4).

Lead I: the negative electrode at the R forelimb, the positive electrode is the L forelimb.
Lead II: the negative electrode is at the R forelimb, and the positive electrode is at the L hindlimb.
Lead III: the negative electrode is at the L forelimb, and the positive electrode is at the L hindlimb.
aVR: the negative electrode is between the L forelimb and L hindlimb, and the positive electrode is the R forelimb.
aVL: the negative electrode is between the R forelimb and L hindlimb, and the positive electrode is the L forelimb.
aVF: the negative electrode is between the R forelimb and L forelimb, and the positive electrode is the L hindlimb.
V1 (CV5RL/RV2): the positive electrode is at the R fifth intercostal space (ICS) near the sternum.

> ***A Note*:** Santilli et al. have proposed a superior location for V1 that more consistently faces the right ventricle (RV) in dogs of all chest conformations. In dolichomorphic (deep-chested) dogs with a vertical heart, V1 at the R fifth intercostal faces the left ventricle (LV) and R waves (not S waves) are seen. In mesomorphic ("normal" chested dogs with a horizontal heart), V1 at the standard location faces the interventricular septum (RS complex). In brachymorphic dogs ("barrel-chested" dogs with a vertical heart), V1 at the fifth ICS gives standard rS complexes and so faces the RV like it should. Thus, the first R ICS at the parasternal

Interpretation of the Electrocardiogram in Small Animals, First Edition. Nick A. Schroeder.

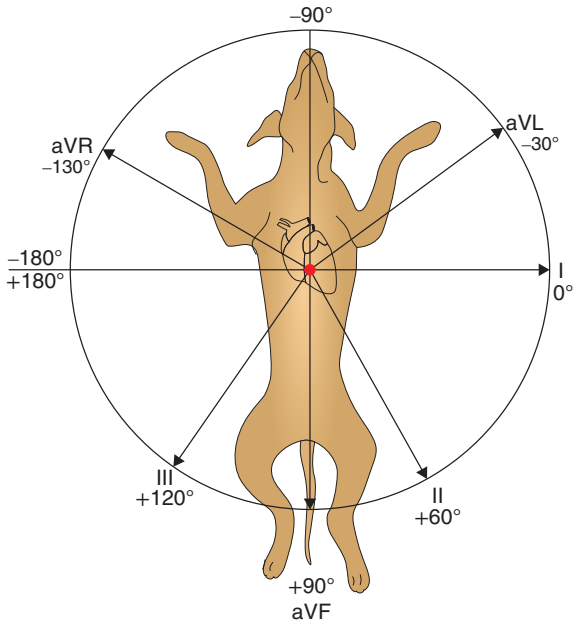


Figure 1.1 Illustration of the limb lead axes in the frontal plane. Lead I is positive at 0 degrees, II is positive at 60 degrees, aVF at 90 degrees, and III at 120 degrees. Lead aVL is positive at −30 degrees and aVR is positive at −130 degrees.

location appears to work best for V1 as it more consistently faces the RV, producing an R/S ratio of <1 and a biphasic P wave. The importance of proper placement of V1 cannot be underestimated, as accurate diagnosis of bundle branch and fascicular blocks of the QRS complex and atrial enlargement patterns is critically dependent on lead positioning.

V2 (CV6LL): the positive electrode is at the L sixth ICS near the sternum.
V3: the positive electrode is placed at the L sixth ICS between V2 and V4.
V4 (CV6LU): the positive electrode is at the L sixth ICS at the costochondral junction.
V5: the positive electrode is at the sixth L ICS above V4, between V4 and V6.
V6: the positive electrode is at the sixth L ICS above V5, between V5 and V7.
V7–V9: in keeping with the same pattern extending to V10.
V10: the positive electrode is at the over the dorsal spinous process of the sixth or seventh thoracic vertebrae.

The negative electrode is the average voltage across leads I, II, and III for the V leads. This is also known as the "V" or Wilson's central terminal, essentially placing the negative pole in the center of the chest. The right precordial leads are designated as RV1-6 and S-T segment elevations in these leads may occur with right ventricular myocardial infarction/ischemia. The left posterior leads (LV7–LV10) may display S-T segment elevations associated with left ventricular posterior infarction/ischemia.If you had a choice, all you need is three leads in three different axes to get a feel for what is going on:

X plane (frontal): Lead I
Y plane (frontal): Lead aVF
Z plane (horizontal): Lead V10; however, lead V1 typically suffices.

A lead is like looking at the shadow of an object on a wall. If it is at one angle, the shadow may be very long, while at another it may be short. If you are looking at it from an entirely different angle, the shadow may point the other way. If you think about EKGs this way, they tend to make a little more sense. The baseline is termed "isoelectric" and without atrial fibrillation, artifact, rapid heart rates, or ventricular fibrillation, the baseline should return to the isoelectric level following each series of deflections that constitute one cycle or heartbeat. If a deflection moves up from the baseline, it is moving toward the positive electrode in whatever lead you are looking at. If the deflection moves

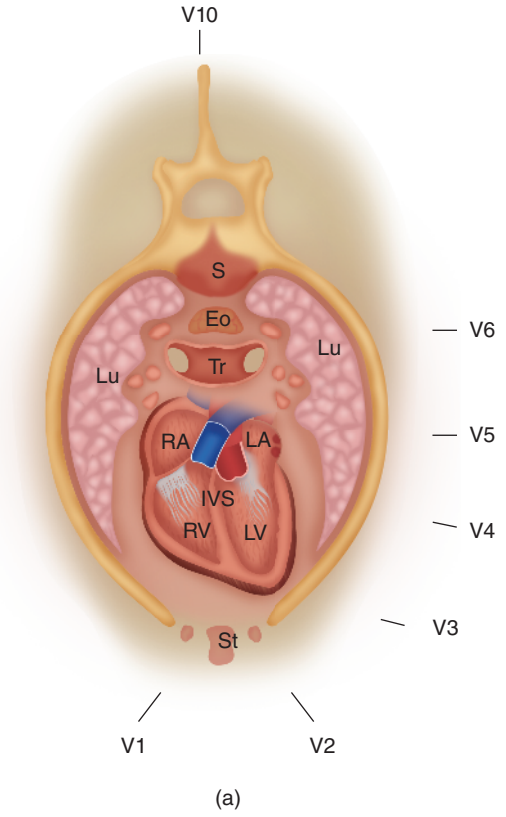
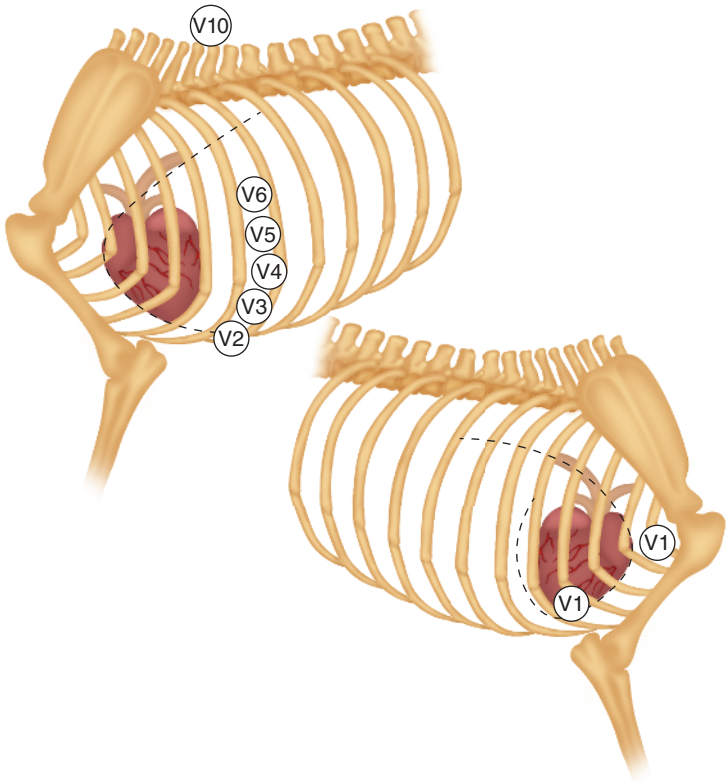


Figure 1.2a Illustration of the precordial lead axes in the horizontal plane: transverse section at the level of the sixth ICS. Lead V1 is positive to the R of midline and V2–V6 are positive to the left. V10 is situated at the dorsal spinous process, and leads V7–V9 are omitted. **S**: spine, **Eo**: esophagus, **Lu**: lung, **Tr**: trachea, **RA**: right atrium, **LA**: left atrium: **RV**: right ventricle, **LV**: left ventricle, **IVS**: interventricular septum, **St**: sternum.



(b)

Figure 1.2b Illustration of the placement of the precordial leads along the sixth ICS. The position of lead V1 at the R fifth ICS near the sternum may be better placed at the first ICS on the right.

down from the baseline, it moves toward the negative electrode in that lead. Strong deflections have greater amplitude (positivity or negativity) than weak deflections. What makes up one cycle of a heartbeat? Here are some definitions.

Waveforms/intervals

The waveforms and intervals/segments make up the pattern seen on surface EKG. Commonly identified waveforms are in bold and commonly assessed intervals are italicized. Some of the waveforms are not normally evident or present, and the QRS complex itself is assessed as a complex of waveforms and also evaluated for duration though not referred to as a specific interval per se.

P wave: atrial depolarization. The entire P wave is the summation of the right and left atrial (LA) depolarizations. The first half is right atrial (RA) depolarization and the last half is LA depolarization. Depolarization is mediated initially by sodium channels. The normal MEA for the P wave in dogs is −18 to +90 degrees (0 to +90 degrees in the cat).

P' wave: Atrial depolarization originating at or above the level of the atrioventricular (AV) node, usually ectopic atrial or junctional, but outside the sinus node. A P' wave has a different morphology than that of the normal sinus P wave and can occur after the QRS if retrograde/ventriculoatrial conduction is present.

Ta wave (also known as the Tp wave): Atrial repolarization may be seen in P-R segment or S-T segment, opposite in polarity of the P wave, associated with RA enlargement, hypoxia, and electrolyte imbalances, and is usually too low in amplitude to be detected in the P-R interval or buried in the QRS complexes. The Ta wave may be seen in second/third degree AV block as it is no longer obscured by an intervening QRS complex.

P-Ta segment: From the beginning of the P wave to the end of the Ta wave. This may be elevated with atrial infarction, leading to P-R elevation if the Ta wave is buried within the QRS complex, aka "PQ elevation." Depression of P-R segment may occur with elevated sympathetic tone.

***P-R interval* (P-Ri)** From the beginning of the P wave to the start of the Q wave (or the R wave if no Q wave is present), the P-Ri represents the delay of the impulse through the AV node. This delay is mediated via slower L-type calcium channels. The P-Ri is normally constant and of a certain duration (0.13 second or less in dogs, 0.06 second or less in cats). If the P-Ri is consistently short (0.03 second or less), then an accessory pathway or retention of rapid juvenile AV nodal conduction is present. If

the P-Ri is prolonged, first degree AV block is present. If two distinct P-R intervals are present, then dual AV nodal physiology is suggested. If a predictable and progressive prolongation before a second degree AV block (P wave without associated QRS complex) occurs, then a Type I second degree AV block is present. If the P-R intervals are completely variable (i.e. no P-Ri is the same as another without any discernable pattern), then AV dissociation is present.

Q wave: First negative deflection after the P wave before a positive deflection. The Q wave represents the initial rightward interventricular septal wall depolarization.

q wave: If less than 0.5 mV in amplitude.

Delta wave: This is a slurring of the upstroke of the R wave, associated with a short P-R interval and ventricular pre-excitation syndromes. The presence of a delta wave indicates the presence an accessory pathway bypassing the AV node.

R wave: The first positive deflection after a negative, actually with or without a Q wave preceding. The R wave represents the endocardial to epicardial depolarization of the ventricles.

r wave: If less than 0.5 mV in amplitude.

S wave: The first negative deflection after the R wave. The S wave represents the final apical to basilar depolarization of the ventricles.

s wave: If less than 0.5 mV in amplitude.

QRS complex: Represents ventricular depolarization. The order of depolarization of the IVS, endocardium to epicardium, then apicobasilar directions correspond to the EKG deflections of Q, R, and S waves, respectively. The QRS complex itself is a summation of right and left ventricular (RV, LV) depolarizations. Given that the LV is normally the more massive of the two chambers, the vector of the LV dominates that of the RV. The QRS complex is initiated by sodium channels. Most of the time, it is more correctly termed qRs given the relative amplitudes of the different waves. The MEA of the QRS complex is normally between +40 and +100 degrees in the dog and between 0 and +160 degrees in the cat.

Intrinsicoid deflection (R peak time): This is the interval from the beginning of the QRS complex to the beginning of the descending branch. Practically, this means from the start of the QRS with or without a q wave to the peak of the R wave (or s/S wave if no R wave present). This interval is used in humans and measured from the precordial leads. The intrinsicoid deflection represents depolarization from the endocardium to the epicardium. Prolongation may occur secondary to ventricular hypertrophy or conduction delay. Normal times for small animals are yet to be definitively established.

S-T segment From the end of the S wave to the start of the T wave, indicating that all regions of the ventricle are depolarized. The S-T segment should be isoelectric, but may be slurred or coved, and significant elevations or depressions from the baseline may indicate myocardial ischemia/infarction or hypoxia.

QS wave: Negative deflection without a positive.

q' wave: The first positive deflection after a positive.

r' wave: The next positive deflection after the S wave before returning to baseline (before the T).

s' wave: The next negative deflection after the S wave before returning to baseline (before the T).

J point: Where the S wave just returns to the baseline, may be elevated or depressed along with S-T segment changes.

Osborn wave: Also known as the J wave, the Osborn wave is a hump where the QRS complex joins the S-T segment and is commonly seen in severe hypothermia along with bradycardia, prolonged P-Ri, QRS duration, and Q-Ti.

Epsilon wave: May be seen in association with arrhythmogenic right ventricular cardiomyopathy, and is best seen in V1 and V2 (occasionally V1–V4). The epsilon wave is a deflection seen within the S-T segment as late potentials (little wiggles) caused by postexcitation of the myocytes in the RV.

***Q-T interval* (Q-Ti)** From the onset of the QRS complex to the end of the T wave, this is the period of ventricular action potential duration and is potassium or sodium channel dependent. The Q-Ti is shorter with a higher HR and longer with a slower HR and is often corrected for the HR (termed QTc interval). Normally from 0.14 to 0.22 second in dogs and up to 0.16 second in cats.

T wave: Ventricular repolarization; technically occurs from the onset of the QRS complex and continues through the end of the T wave. The T wave is not caused by a propagated wave and should be approximately ¼ the amplitude of the R wave, positive in V1 and negative in V10 (mediated via potassium channels). The MEA of the T wave in dogs and cats is generally not calculated as its axis may be concordant or discordant with the MEA of the QRS and may vary even within individuals, essentially rendering the calculation irrelevant.

U wave: A deflection following the T wave usually in the same direction as the T wave. The U wave was previously attributed to m cells (ventricular myocytes located in the midmyocardium with very long action potentials), and has been also theorized to result from repolarization of Purkinje fibers and potentials formed during isovolumetric relaxation. U waves are associated with long Q-T syndromes (LQTS), hypokalemia, and bradycardia. U waves may be mistaken for non-conducted sinus or ectopic atrial beats.

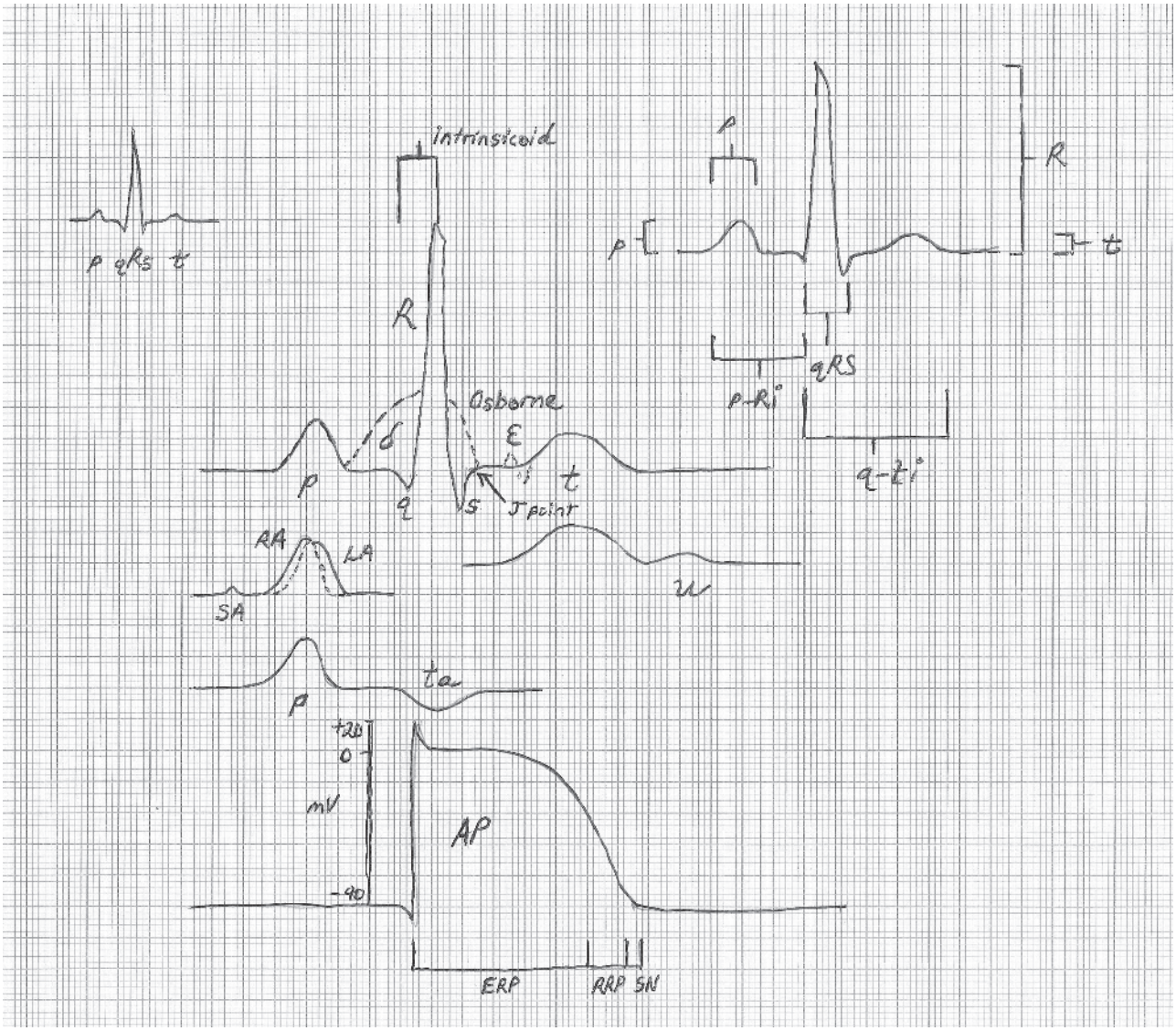
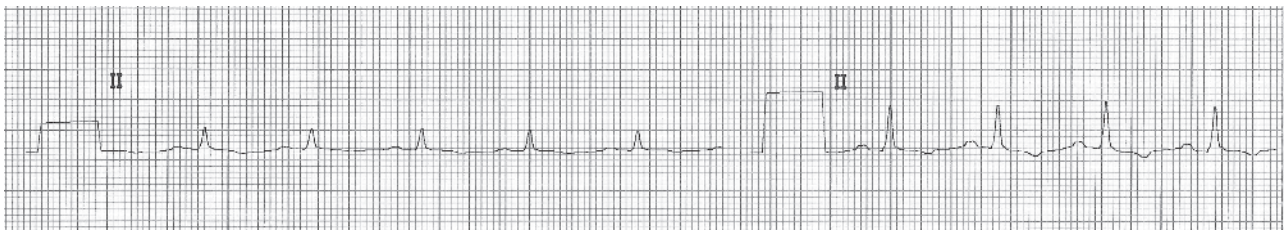


Figure 1.3 Illustration of the waveforms and intervals. **P**: p wave, **q**: q wave, **R**: R wave, **s**: s wave, **t**: t wave, **qRs**: QRS complex, **δ**: delta wave, **ε**: epsilon wave, **SA**: sinoatrial depolarization, **RA**: right atrial depolarization, **LA**: left atrial depolarization, **ta**: Ta wave, **u**: U wave, **P-Ri**: P-R interval, **q-Ti**: Q-T interval, **AP**: action potential, **ERP**: effective refractory period (absolute refractory period), **RRP**: relative refractory period, **SN**: supernormal period.

Amplitudes

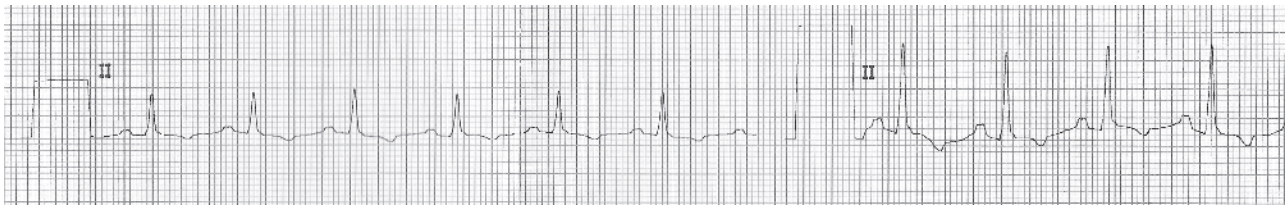
How tall (positive) or deep (negative) is termed the amplitude of a wave. As measured from the baseline, a positive wave is deflected upward, and means the impulse is directed toward the positive pole in that lead at that instant. A negative wave is deflected downward and means the impulse is directed toward the negative pole in that lead at that instant. We measure the amplitude of a wave in millivolts. A calibration mark is typically created by the machine immediately before a tracing and tells us the scale. By convention, one centimeter on the strip (one large box) equals one millivolt (1 cm/mV or 10 mm/mV). Just remember to check the sensitivity prior to measuring the amplitudes, so the measurement is correct. The amplitude of a wave is measured from the baseline (zero voltage, isoelectric line) to the most positive or negative point.

1 cm/mV (10 mm/mV) is standard.
0.5 cm/mV (5 mm/mV) or half-sensitivity makes the complexes smaller.
2 cm/mV (20 mm/mV) or double-sensitivity makes the complexes taller.



(a)

Figure 1.4a Paper speed 50 mm/s, lead II, canine. Comparison of half-sensitivity to full-sensitivity. Note the calibration marks. Both are 1 cm wide indicating a consistent paper speed of 50 mm/s. The first has an amplitude of 0.5 cm tall corresponding to **0.5 cm/mV**, and the second has an amplitude of 1 cm indicating **1 cm/mV**. Note all waveforms have the same duration, but the second set of waveforms is twice as tall. Lower sensitivity makes the waveforms more difficult to tell apart.



(b)

Figure 1.4b Paper speed 50 mm/s, lead II, same dog. Comparison of full-sensitivity to double-sensitivity. Again, note the calibration marks. Their widths are the same at 1 cm, alerting the examiner that the paper speed is 50 mm/s. The first has an amplitude of 1 cm (**1 cm/mV**), and the second has an amplitude of 2 cm (**2 cm/mV**), so the complexes are again now twice as tall. Higher sensitivity exaggerates the complexes and makes it easier to measure *amplitudes*, but it does amplify any underlying baseline artifact as well. The QRS complexes are all approximately *0.8* mV.

Paper speeds

The duration of a wave refers to the total time it takes to return to baseline and is a function of how fast the paper speed is. The heart rate may be calculated a few different ways. If the rhythm is perfectly regular, then instantaneous heart rates (i.e. using an R-R interval) can be calculated. If the rhythm is irregular, then a longer duration of time should be used (i.e. 3–6 seconds).

At 25 mm/s: Standard for humans – 1 small box is 0.04 second and 1 big box is 0.2 second
1500/# of small boxes in one R-R interval = bpm
300/# of big boxes in one R-R interval = bpm
# of beats in one pen length (approximately 30 big boxes or 6 seconds) × 10 = bpm
So at 100 bpm, there should be 15 little boxes (or 3 big boxes) between R waves.

> ***Quick and Dirty***: At 25 mm/s, if you find an R wave on a bold line on the EKG paper, and the next R wave is 1 big box away, the HR is 300 bpm. If the next R wave is 2 big boxes away, the HR is 150 bpm. If the next R wave is 3 big boxes away, the HR is 100 bpm. If the next R wave is 4 boxes away, the HR is 75 bpm. If the next R wave is 5 boxes away, the HR is 60 bpm. If the next R wave is 6 boxes away, the HR is 50 bpm. "1-2-3-4-5-6 is 300-150-100-75-60-50 bpm."

50 mm/s: Is standard for small animals – 1 small box is 0.02 second and 1 big box is 0.1 second
3000/# of small boxes in one R-R interval = bpm
600/# of big boxes in one R-R interval = bpm
# of beats in one pen (approximately 30 big boxes or 3 seconds) length × 20 = bpm
So at 100 bpm, there should be 30 little boxes (or 6 big boxes) between R waves.

It is best to evaluate the EKG in the following manner. However it is done, it is best to do it systematically in the same manner every time.

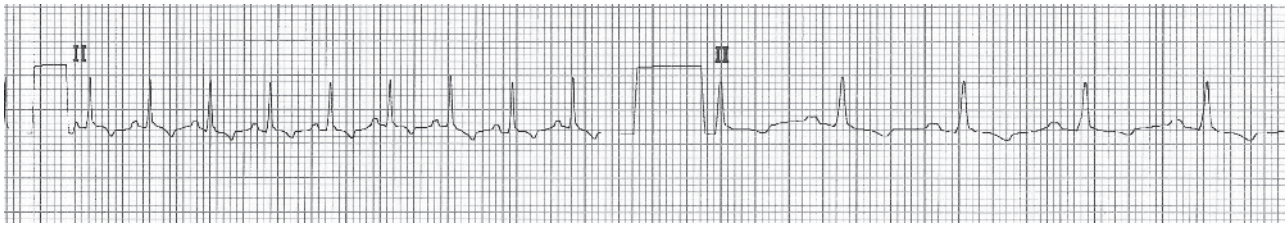
Rate: Is the rate normal or abnormal? Too fast? Too slow? Calculate the HR.

Rhythm: Regular or irregular? Regularly irregular ("allorhythmia" – or a regularity within an irregularity, most often respiratory sinus arrhythmia, premature beats with consistent pauses?), irregularly irregular (atrial fibrillation? frequent and multifocal premature beats?). *Too* regular (pacemaker, ectopic tachycardia)?

P waves?: Present? Not present? (look in other leads, consider atrial fibrillation, atrial standstill).

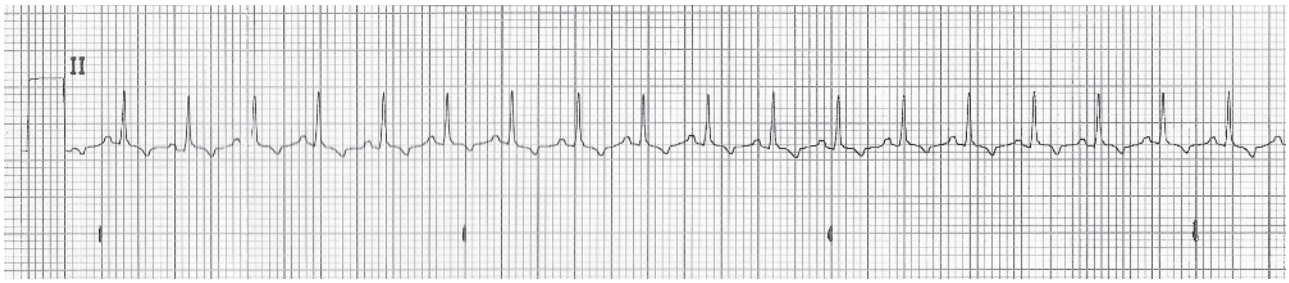
P for every QRS?: If not, consider premature beats.

QRS for every P?: If not, consider AV block.



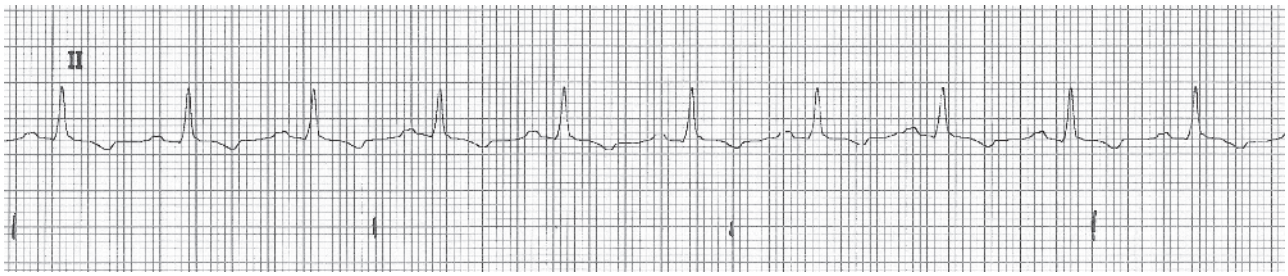
(a)

Figure 1.5a Amplitude 1 cm/mV, lead II, canine. Comparison of paper speeds. Note the calibration marks preceding the recordings. Both are at the same amplitude of 1 cm, indicating 1 cm/mV. The first is only 0.5 cm wide, alerting the examiner that the paper speed is **25 mm/s**. The second is 1 cm wide, indicating the paper speed is now **50 mm/s**. The faster paper speed stretches out the waveforms, making the measurement of *intervals* easier. The R waves are nearly 4 big boxes apart at 50 mm/s, indicating the heart rate is just over *150* bpm.



(b)

Figure 1.5b Amplitude 1 cm/mV, paper speed 25 mm/s, lead II, same dog. More accurate calculation of the heart rate can be made by counting the number of complexes in a 6 second period. Thirty big boxes are counted out and 17 complexes are counted within this interval. The heart rate is therefore calculated as 17×10 or *170* bpm.



(c)

Figure 1.5c Amplitude 1 cm/mV, paper speed 50 mm/s, lead II, same dog. Calculation of the heart rate is calculated as nine complexes within a 3 second period or $9 \times 20 = 180$ bpm. Given the very regular rhythm, a more accurate estimation of heart rate is calculated as: 3000/18 little boxes between R waves or *167* bpm. Practically speaking, the difference between 167, 170, and 180 bpm is clinically unimportant.

Measurements: Any RA or LA abnormalities, right or left ventricular enlargement, bilateral atrial enlargement, or biventricular enlargement?

P MEA: Is it normal or abnormal? Consistent with sinus focus, R or L atrial focus, junctional/retrograde conduction?

QRS MEA: Is it normal or abnormal? Right axis deviation (RAD) or left axis deviation (LAD)? Extreme axis deviation?

Q-Ti: Is it normal? Prolonged/shortened QRS complex or S-T segment? S-T segment deviations?

Arrhythmias and conduction abnormalities will be discussed elsewhere. Never forget the importance of independently calculating the atrial and ventricular heart rates, though keep in mind that the ventricular rate has more hemodynamic importance. Remember when interpreting the heart rate, ask yourself if it is appropriate for the given situation? Dogs that are healthy may have a phasic

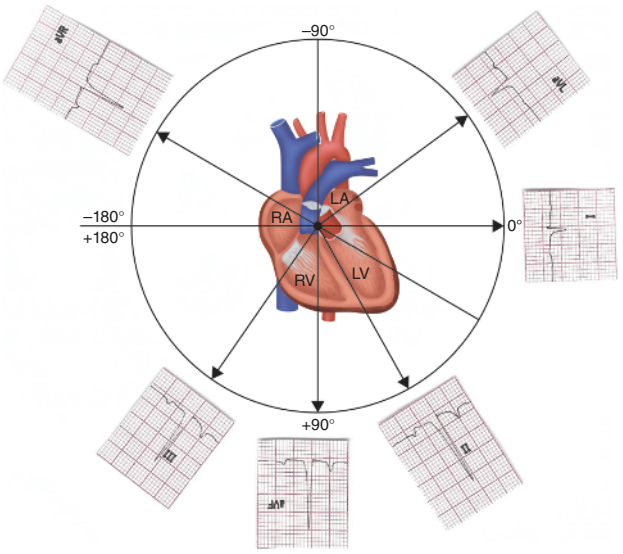
respiratory sinus arrhythmia, and nervous cats in the exam room usually have sinus tachycardia. If the heart rate is inappropriate for the situation, consider pathologic states. Remember that common things occur commonly. Never forget this.

Mean electrical axis The MEA of the QRS reflects the main vector of ventricular depolarization, and the MEA of the P wave similarly describes the vector of the atrial depolarization. Ventricular enlargement or ectopy may change the MEA of the ventricles, and atrial enlargement or ectopy may alter the axis and appearance of the P wave.

The MEA of the QRS complex can be a tricky thing for new veterinarians to deal with, and it is really not all that difficult. However, you need more than one lead to determine the MEA. There are two easy ways to determine the MEA. The thing to realize is that the circle in the frontal plane is arbitrarily 0 degrees at lead I (straight to the patient's L) and proceeds +180 degrees clockwise (caudally) and −180 degrees counterclockwise (cranially).

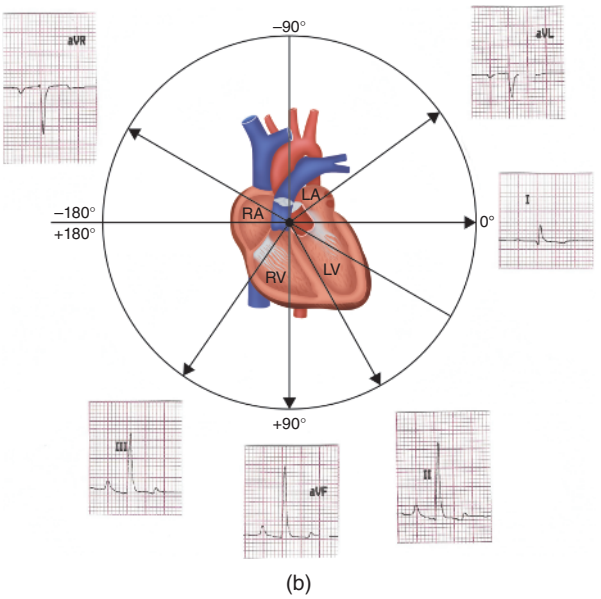
Lead I: 0 degrees
Lead II: +60 degrees
Lead aVF: +90 degrees
Lead III: +120 degrees
Lead aVL: −30 degrees
Lead aVR: −160 degrees

If you find the most isoelectric lead (the one with the positive and the negative deflections approximately equal to each other, RS or rs complexes) and go 90 degrees in the direction of the most positive leads, this will give you the MEA. Another method is to use two leads that are perpendicular to each other (i.e. lead I and aVF or lead II and aVL), count the positive and the negative units of amplitude (small boxes) in one complex of each lead on the EKG and count out the number of units from the center of the circle along that lead equal to the number you came up with (e.g. +10 added to −5 boxes results in a net +5 boxes). Drawing a line perpendicular to that lead at that level of units and do it with the other lead you are looking at. Find where those lines intersect on each lead, and where they bisect gives you the MEA. Another easy way to figure out which quadrant the mean QRS vector resides in is to check leads I and aVF, which are perpendicular to each other. If the QRS complex in lead I is positive, then the mean QRS is between −90 and +90 degrees. If the QRS complex in lead I is negative, then the mean QRS is between +90 and −90 degrees. If the QRS complex in lead aVF is positive, then the mean QRS vector is between 0 and +180 degrees. If the QRS complex lead aVF is negative, then the mean QRS vector is between 0 and −180 degrees. Checking the axis of the QRS in these two leads quickly tells you which quadrant the MEA of the QRS is located in.



(a)

Figure 1.6a Illustration of the limb leads with superimposed EKG from a normal canine. The angle of the tracing reflects the direction of the positive pole in each lead.



(b)

Figure 1.6b Illustration of the limb leads with superimposed EKG from the same dog. Here, the angles are situated normally. We know the MEA here is likely closest to aVF, given the R waves have the greatest magnitude in that lead. We also know the MEA must be between 0 and +90 degrees, given that the QRS complexes are positive in leads I and aVF. Lead I is most isoelectric and going 90 degrees in the direction of the most positive leads puts the MEA close to +90 degrees.

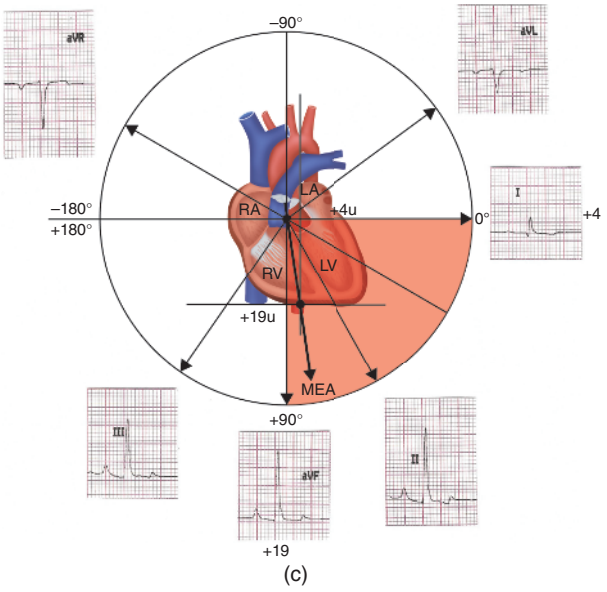


Figure 1.6c Illustration of the limb leads with superimposed EKG from the same dog. Calculation of the MEA is made using leads I and aVF. In lead I, the R wave is 4 little boxes tall in amplitude. Four units toward the positive pole in lead I are counted out. In lead aVF, the R wave is 19 small boxes tall in amplitude. Nineteen boxes are counted out toward the positive pole. Where perpendicular lines to each lead at their respective levels intersect is where the MEA of the QRS is. In this case, the MEA is approximately +80 degrees.

Left axis deviation suggests left ventricular enlargement, hypertrophy, or aberrancy and RAD suggests right ventricular enlargement, hypertrophy, or aberrancy. If the mean QRS vector lies between 0 and −90 degrees, LAD is present. If the mean QRS vector lies between 90 and +180 degrees, RAD is present. If the mean QRS vector lies between +180 and −90 degrees, extreme axis deviation ("no man's land") is present.

Normal dogs have a MEA of +40 to +100 degrees.
LAD if the MEA < +40 degrees
RAD if the MEA > +103 degrees
Normal cats have a much wider MEA of 0 to +160 degrees.
LAD if the MEA <0 degrees
RAD if the MEA > +160 degrees

Quick and Dirty: Find the lead with the most positive QRS, and the MEA is likely close to that. If the QRS is positive (upright) in leads II, III, and aVF (the inferiors), then the axis is probably normal. The P waves should be positive in lead I and negative in lead aVR. This indicates that atrial depolarization began from a superior position on the right, consistent with an impulse generated anatomically within the sinoatrial node in the right atrium. The leads are likely on correctly if the P waves are oriented normally.

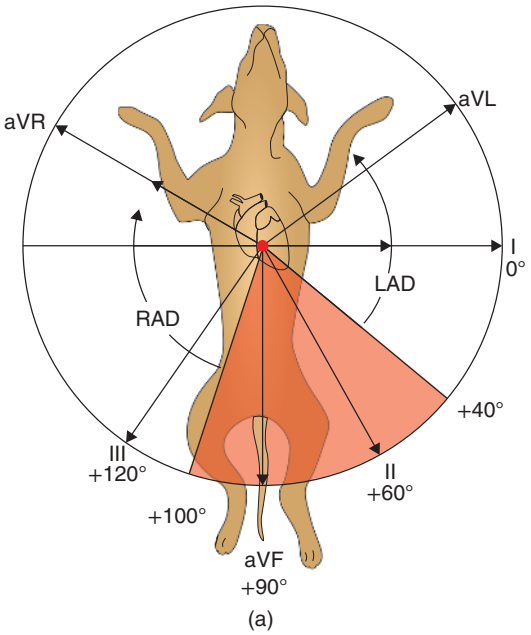


Figure 1.7a Illustration of the canine normal mean electrical axis of the QRS. The normal MEA ranges between +40 and +100 degrees. As such, the QRS complexes should be positive in I and aVF if the MEA is between 0 and +90 degrees. Most of the time, lead II provides the tallest amplitude QRS complexes, which is why it is commonly used as a monitoring lead. The QRS complexes should always be negative in aVR and aVL if the MEA is within normal limits and are usually positive in the inferiors (II, III, and aVF).

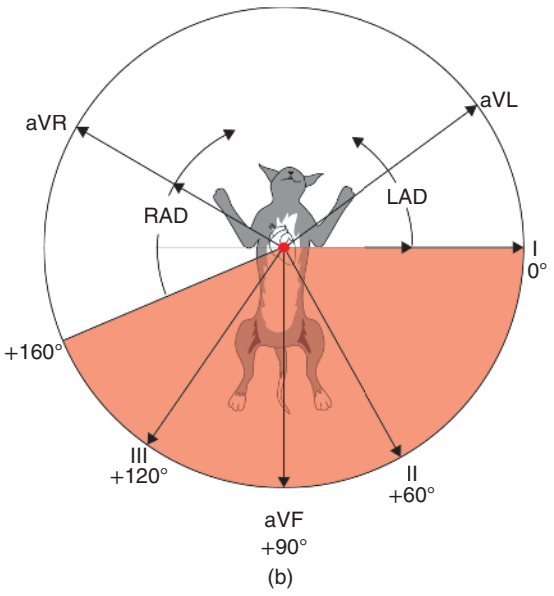
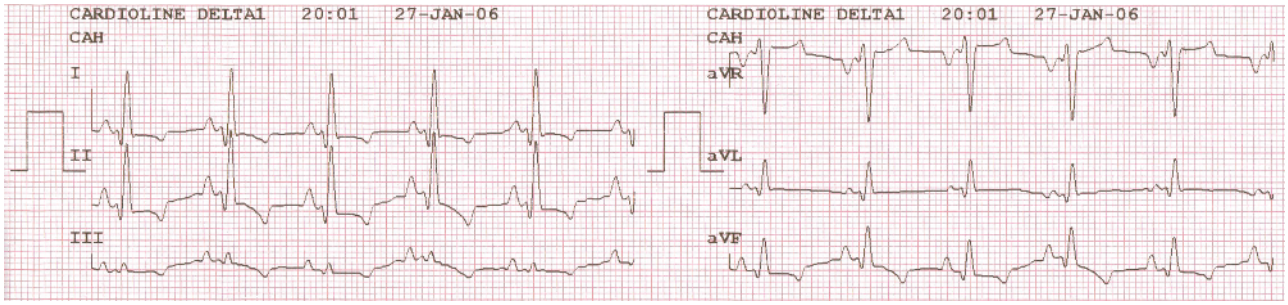
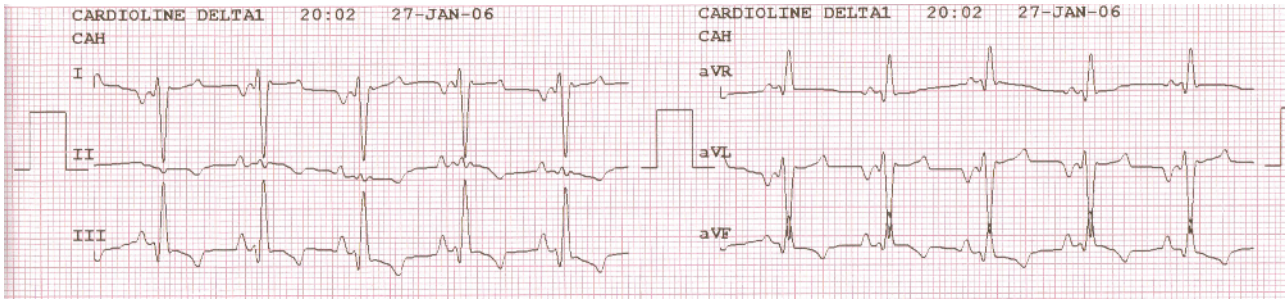


Figure 1.7b Illustration of the feline normal mean electrical axis of the QRS. The normal MEA in the cat is wider and ranges between 0 and +160 degrees. As such, the QRS complexes should be positive in I and aVF if the MEA is between 0 and +90 degrees. The QRS complexes should be negative if aVR and aVL and positive in the inferiors (II, III, and aVF) if the MEA is within normal limits.



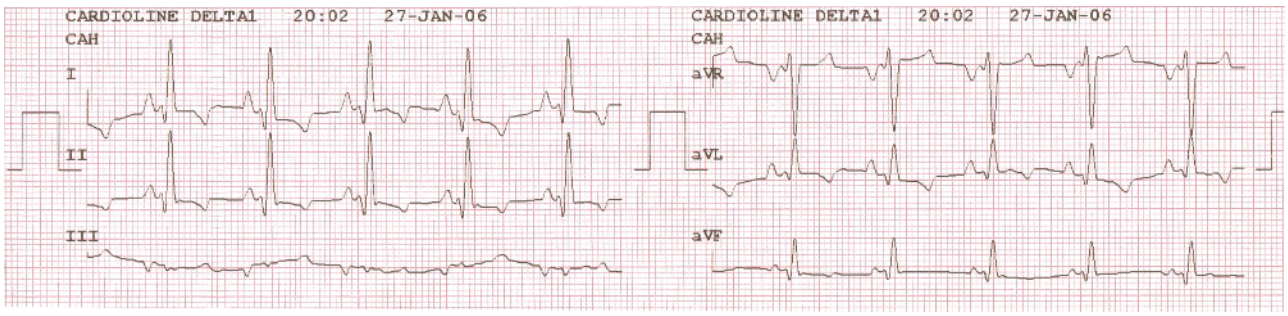
(a)

Figure 1.8a Paper speed 50 mm/s, 1 cm/mV, full EKG, canine. **Normal sinus rhythm** (NSR). This is a **normal** EKG with a **normal** MEA. The P waves are positive in I and aVF, and negative in aVR, indicating a normal P wave axis. The QRS complexes are positive in I, II, III, aVF (and aVL).



(b)

Figure 1.8b Paper speed 50 mm/s, 1 cm/mV, full EKG, same dog. **False poling** (the leads are placed incorrectly). The clue is that the P wave MEA is abnormal. The P waves are positive in aVR and negative in lead I, which over 99%of the time indicates false poling (less than 1% of the time in humans indicates atrial ectopy or *situs inversus* – see below). The **RA** (white) and **LA** (black) electrodes have been *switched*. This essentially switches aVR and aVL, turns lead II into lead III, lead III into lead I, and inverts lead I. This is the most common error in lead placement, a pattern that mimics **situs inversus**.



(c)

Figure 1.8c Paper speed 50 mm/s, 1 cm/mV, full EKG, same dog. False poling. The **LA** (black) and **LL** (red) electrodes have been *switched*. Leads I and aVR look normal in this case, so looking at the P waves in these leads is not helpful. The clue here is that there appears to be L axis deviation with a MEA of approximately +30 degrees, and the P waves are *negative* in lead III. P waves should be positive in I, II, and aVF, negative in aVR, and are usually positive in III (but can be negative). This dog has no other EKG criteria consistent with LVH (normal amplitude and duration of the QRS complexes) that would otherwise support a left axis deviation. Switching the LA and LL electrodes effectively inverts lead III, reverses aVL and aVF, and reverses I and II.

False poling When the leads are incorrectly applied to the animal, this is termed false poling. The most common error is switching the left and right forelimb leads, which simulates situs inversus (see below). Always verify correct placement of the leads prior to recording an EKG.

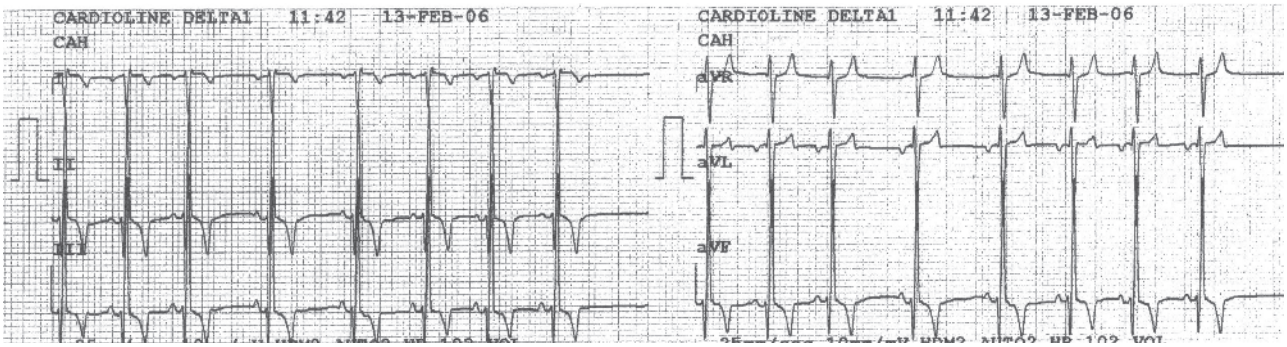
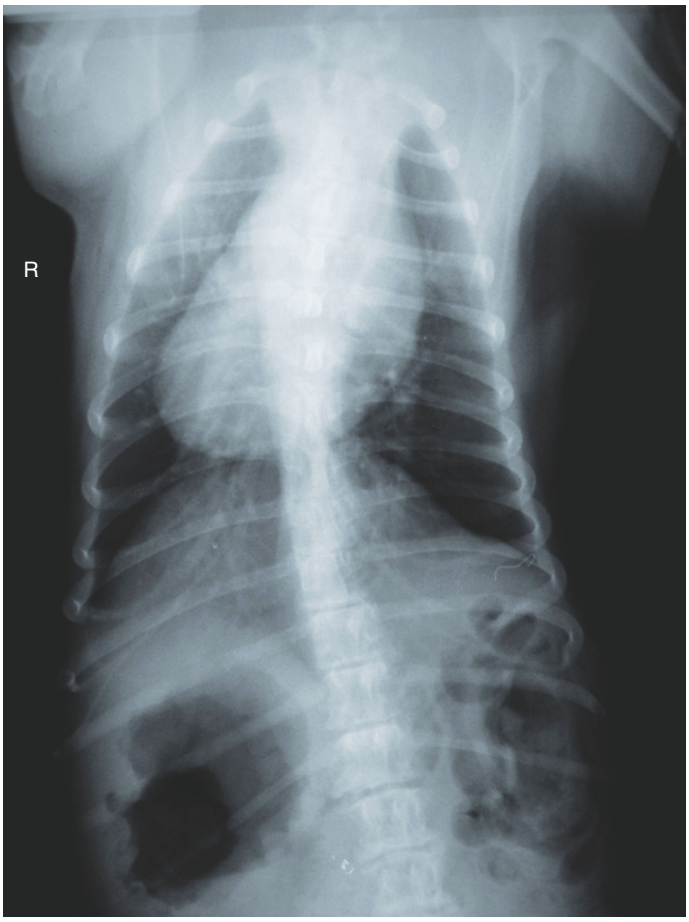


Figure 1.9a Paper speed 25 mm/s, 1 cm/mV, full EKG, canine with **situs inversus**. The P waves are *negative* in lead I, which is the only situation in which this would be a "normal" and expected finding, since this patient's heart and internal organs are reversed or the "mirror image" of normal. In cases of situs inversus, the SAN is in the "RA" which is *anatomically* on the left side of the body, so the P waves are directed from L to R, and would thus be negative in lead I. Note that aVL has negatively oriented P waves, and the QRS complexes in I are negative from RAD. Despite the fact that these are *abnormal* findings on surface EKG, this pattern is *normal* for a patient with situs inversus.

Figure 1.9b Ventrodorsal radiograph from the same dog. **Situs inversus**. The standard view shows a mirror image of normal with the cardiac apex and gastric fundus is on the right.



Situs inversus This is a very rare condition where the internal organs are reversed (mirror image) from normal. Dextrocardia is present so the apex of the heart will be on the right and the right atrium/sinus node is anatomically located on the left. Situs inversus therefore creates a unique EKG pattern with negative P waves (provided sinus rhythm) in lead I. The MEA of the QRS will be slightly deviated to the right. Dextropositioning of the heart, as what can happen in isolation or association with severe left ventricular enlargement may show some minor axis shift of the QRS, but sinus P waves should still be positive in lead I. Situs inversus is commonly misdiagnosed from false poling of the limb leads on EKG or mislabeled thoracic radiographs.

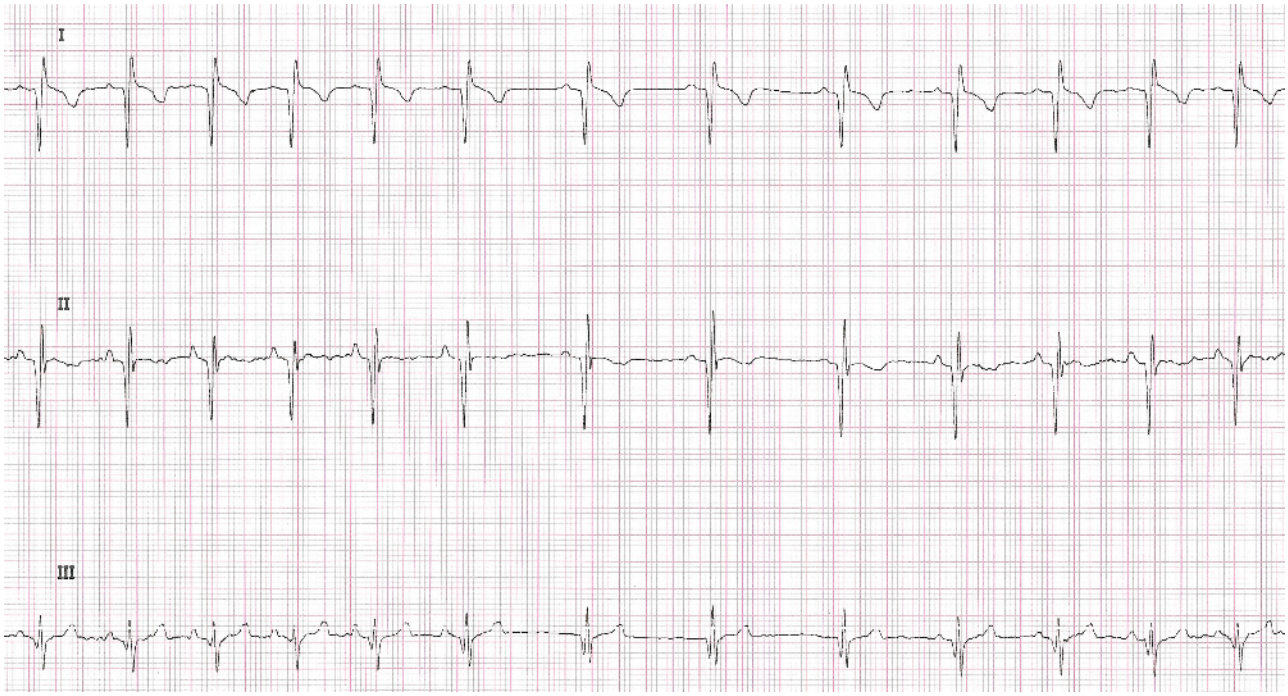


Figure 1.10a Paper speed 50 mm/s, 1 cm/mV, leads I, II, III, canine with isolated **dextropositioning**. A right axis deviation of the QRS is apparent with S waves in leads I and II and an s wave in III. Note the P waves are still positive in lead I, indicated a normal R to L P wave axis.

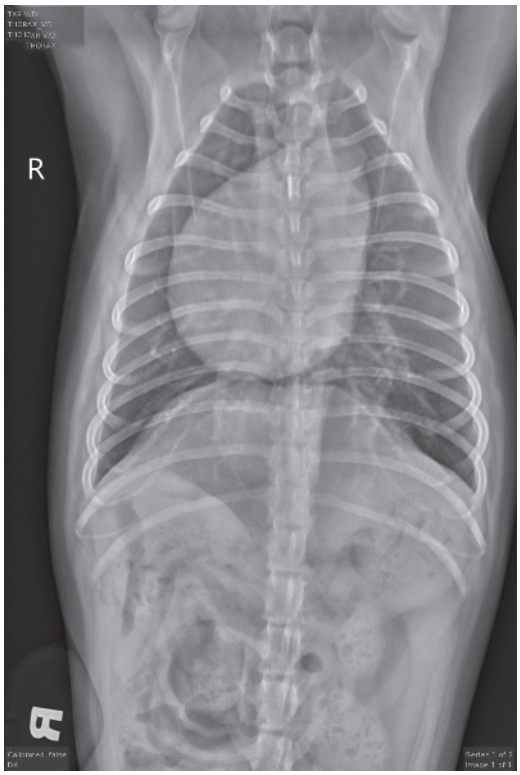


Figure 1.10b Ventrodorsal radiograph from the same dog. **Isolated dextropostioning**. The cardiac apex is deviated to the R hemithorax and the gastric fundus is on the left. This dog had otherwise cardiac anatomy evident on echocardiography, albeit with malpositioning of the cardiac apex to the right.

Further reading

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