2. Electrocardiographic evaluation of chamber enlargement

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General comments

Cardiac chamber enlargement cannot be determined reliably in the horse and cow from the electrocardiogram (ECG) (1). **The following discussion therefore applies only to the dog and cat.**

The following variables must be determined to evaluate for the presence of cardiac chamber enlargement.

1. Determine the ventricular rate:
   note the paper speed
2. Determine the atrial rate:
   note the paper speed
3. Assess atrial enlargement:
   measure P wave duration and amplitude in lead II
   note paper speed
   note sensitivity (calibration)
4. Assess ventricular enlargement:
   a) measure QRS duration in lead II
      note paper speed
   b) measure R wave amplitude in lead II
      note sensitivity
   c) examine for S waves in leads I, II and III
   d) examine for an S wave in lead V_3 and determine its amplitude
      note sensitivity
   e) determine the mean electrical axis of the QRS complex in the frontal plane
   f) examine the ST segment in lead II

Calculation of the ventricular rate

1. Rule off a six-second interval on the ECG that is uninterrupted. Determine the number of complex intervals that occur in this six-second period and multiply this number by 10. This gives the ventricular rate in beats per minute. Note that the R to R intervals are counted and not the number of QRS complexes themselves. To count the number of QRS complexes themselves results in an overestimation of the ventricular rate by up to 10 beats per minute.
2. If the ventricular rhythm is regular, the ventricular rate can be determined by dividing 60 by the R to R interval measured in seconds.

Calculation of the atrial rate

1. The atrial rate is equal to the ventricular rate if there is a P wave for every QRS complex and no extra P waves.
2. If there is not a P wave for every QRS complex or there are extra P waves (P waves that are not followed by a QRS complex), the atrial rate is determined by counting the number of P to P intervals present in a six-second period and multiplying this number by 10. If the P to P interval is regular throughout then the atrial rate can be determined by dividing 60 by the P to P interval measured in seconds.

General comments

As diagnosticians, it always behooves us to understand the accuracy of a test. This is usually expressed in terms of the sensitivity and specificity of the test. In addition to these indices, the predictive value of a positive test result and the predictive value of a negative test result are of particular clinical relevance (2). It should be noted that there have been no definitive studies establishing the sensitivity, specificity, or predictive value of the electrocardiographic criteria to predict the presence of cardiac chamber enlargement.

The **sensitivity** of a test gives us an index of the ability of a test to detect abnormality. The **specificity** of a test gives us an index of the ability of the test to identify a normal patient. The **predictive value of a positive test** indicates the likelihood that a positive result is true. The **predictive value of a negative test** indicates the likelihood that a negative result is true. One can readily appreciate the attractiveness of the predictive value results of a test; they give us a level of confidence about a positive or negative test result.

Based on clinical experience, we have attempted to estimate the relative values for the sensitivity, specificity, and predictive value of each of the chamber enlargement criteria we will discuss.

Determination of atrial enlargement

Electrocardiographic determination of atrial enlargement is made by evaluation of the amplitude and dura-

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Table 1. Electrocardiographic criteria for the diagnosis of cardiac chamber enlargement in the dog and cat

Cardiac Chamber	Variable	Dog	Giant dog	Cat	
Left atrium	P duration	>0.4 sec	>0.045 sec	>0.04 sec	
Right atrium	P amplitude	>0.4 mv	>0.4 mv	>0.2 mv	
Cardiac Chamber	**Variable**	**Small dog**	**Large dog**	**Giant dog**	**Cat**
Left ventricle	R_{II} amplitude	>2.5 mv	>3.0 mv	>3.0 mv	0.9 mv
	QRS duration	>0.05 sec	>0.06 sec	>0.65 sec	Unknown
Right ventricle	MEA of QRS	110° to −80°	110° to −80°	110° to −80°	160° to −80°
	S_I, S_{II}, S_{III}	Yes	Yes	Yes	Unknown
	Sv_3 amplitude	>0.7 mv	>0.7 mv	>0.7 mv	Unknown
	Sv_3 amp $>Rv_3$ amp	Yes	Yes	Yes	Unknown

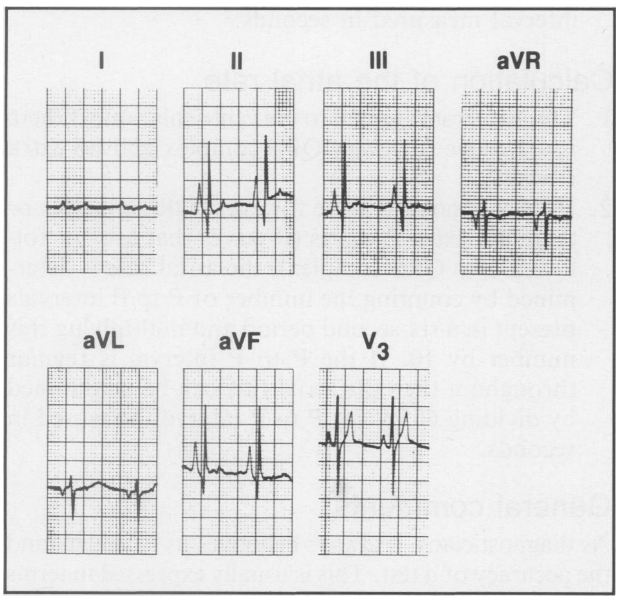

Figure 1. A seven-lead ECG was obtained from a two-year-old female Labrador dog (25 mm/sec, 1 cm = 1 mv). The amplitude of the P wave in lead II is 0.7 mv (7 boxes), indicating right atrial enlargement. The duration of the P wave in lead II is 0.06 sec (1.5 boxes), indicating left atrial enlargement. Biatrial enlargement is therefore diagnosed from this ECG.
As for the presence of ventricular enlargement, the R wave amplitude in lead II is 1.9 mv (19 boxes), and the mean electrical axis (MEA) in the frontal plane of the QRS is about 90°. These findings suggest the absence of left ventricular enlargement.
As well, in the frontal plane there is no evidence for right ventricular enlargement; that is, an S wave is not present in leads I, II and III, and the MEA is not shifted to the right. However, in the horizontal plane V_3, there is a deep S wave (1.3 mv, 13 boxes) which provides strong evidence for the presence of right ventricular enlargement.
This dog had pulmonic stenosis with right ventricular and right atrial enlargement.

tion of the P wave in lead II. All of the criteria for chamber enlargement are summarized in Table 1.

Determination of left atrial enlargement

The presence of a P wave that is too wide fulfils the electrocardiographic criterion for left atrial enlargement (Figure 1).

for the dog and cat; P wave > 0.04 sec (3,4)
for the very large dog; P wave > 0.045 sec

It is our impression that the sensitivity of the ECG criterion for left atrial enlargement is rather low while the specificity of this criterion is very high. Thus we frequently observe dogs with other evidence (radiographic or echocardiographic) of left atrial enlargement that do not demonstrate a P wave that is too wide. However if a patient demonstrates ECG evidence of left atrial enlargement, it is our impression that the likelihood of really having left atrial enlargement is high (thus the predictive value of a positive test is very high).

Determination of right atrial enlargement

The presence of a P wave that is too tall fulfils the electrocardiographic criterion for right atrial enlargement (Figure 1).

for the dog; P wave > 0.4 mv (5)
for the cat: P wave > 0.2 mv (4)

It is our impression that the sensitivity of this test to detect right atrial enlargement is very low and that the specificity is moderate to high. Furthermore we believe the predictive value of a positive test is low to moderate, that is, a tall P wave frequently occurs in pulmonary disease without evidence of right atrial enlargement (5).

What about biatrial enlargement?

The electrocardiographic criteria of biatrial enlargement are a P wave that is too tall and too wide in lead II (6) (Figure 1).

Comment

1. In the presence of the sinus rhythm known as "wandering atrial pacemaker", the P waves are of various amplitudes which may result in some P waves with an amplitude in excess of 0.4 mv. In the face of wandering atrial pacemaker it is inappropriate to select tall P waves for measurement, and the P wave amplitude measurement should be ignored.
2. All measurements are performed from lead II. It is highly recommended that all duration measurements be performed at a paper speed of 50 mm/

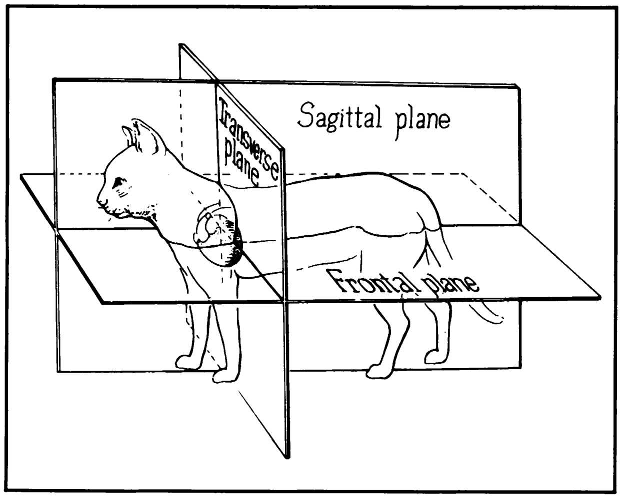

Figure 2. The frontal, left sagittal, the transverse or horizontal planes are illustrated in the cat. Leads I, II, III, aVR, aVL, and aVF are frontal plane leads. Leads V_1, V_2, V_3, V_4, V_5, V_6, and V_{10} are horizontal (or transverse) plane leads. (From: Coulter DB, Calvert CA. Orientation and configuration of vectorcardiographic QRS loops from normal cats. Am J Vet Res 1981; 42: 282, reproduced with permission.)

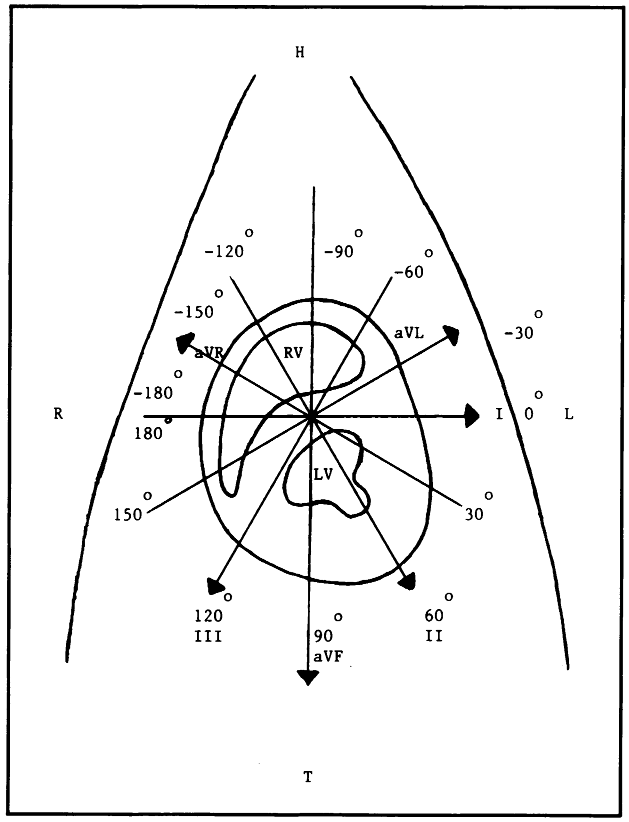

Figure 3. A cross-section of the heart is superimposed on the frontal plane diagram. The arrowheads on each lead point toward the positive pole of that lead.
The frontal plane diagram shows the relationship of the six leads in the frontal plane. This diagram includes the angles in the frontal plane and the direction of each lead with its negative and positive pole.
The frontal plane corresponds to the radiographic V/D or D/V view of the heart.
RV = right ventricular lumen, LV = left ventricular lumen.

sec which should minimize the error with small measurements.

Determination of ventricular enlargement

To determine the electrocardiographic presence of ventricular enlargement one must be familiar with several ECG features:

- the identification of S waves,
- the mean electrical axis of the QRS complex in the frontal plane,
- the horizontal plane lead V_3 and the presence of S waves in this lead.

The identification of S waves

For a deflection of the QRS to be defined as an S wave it must fulfil the following criteria:

a) it must be a negative deflection, **and**
b) it must follow an R wave.

When we search for S waves, QS waves are interpreted as are S waves. For a wave to be defined as a QS wave it must fulfil the following criteria:

a) it must be a negative deflection, **and**
b) there must be no R wave in the QRS complex.

Thus a QS wave refers to a QRS complex with only one deflection and this deflection is negative.

What is the frontal plane and frontal plane diagram?

The frontal, left sagittal, and transverse (better known as the horizontal) planes are illustrated in the cat in Figure 2. The frontal plane contains the common leads I, II, III, aVR, aVL, and aVF. The frontal plane diagram shows the relationship of these six leads with respect to the left and right ventricle in the frontal plane (Figure 3). This diagram includes the angles in the frontal plane and the direction of each lead with its negative and positive pole. The frontal plane diagram is necessary to determine the mean electrical axis in the frontal plane.

Determination of the frontal plane mean electrical axis

A mean electrical axis (MEA) can be determined to describe the atrial depolarization (P wave), ventricular depolarization (QRS complex), and ventricular repolarization (T wave), in the frontal plane and the horizontal plane (also called transverse plane). Typically in veterinary medicine, the MEA is usually only determined for ventricular depolarization in the frontal plane.

The MEA of the QRS complex describes the net or average direction of the wave of activation, or depolarization, of the ventricles. In states that show a normal sinus rhythm, the MEA will point toward the ventricle which is largest. One can see from Figure 3 that the left ventricle is clearly larger than the right ventricle and is situated between about 30° and 120°. Thus normally, the MEA of the QRS in the frontal plane is directed toward the left ventricle (**40° to 110° in the dog and −5° to 160° in the cat**) (7). In disease states that result in enlargement of the right ventricle, the MEA is altered from normal such that it is directed toward the right heart since now the right ventricle is

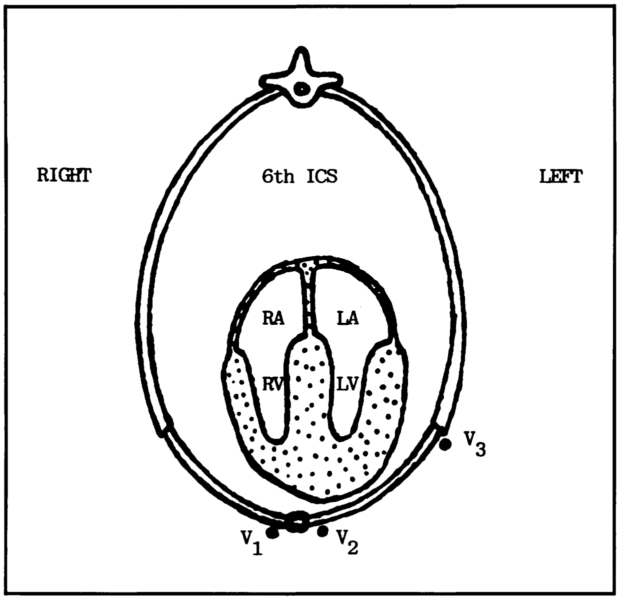

Figure 4. The position of the precordial leads V_1, V_2, and V_3 in the horizontal plane is illustrated.
RA = right atrium, RV = right ventricle, LA = left atrium, LV = left ventricle, ICS = intercostal space.

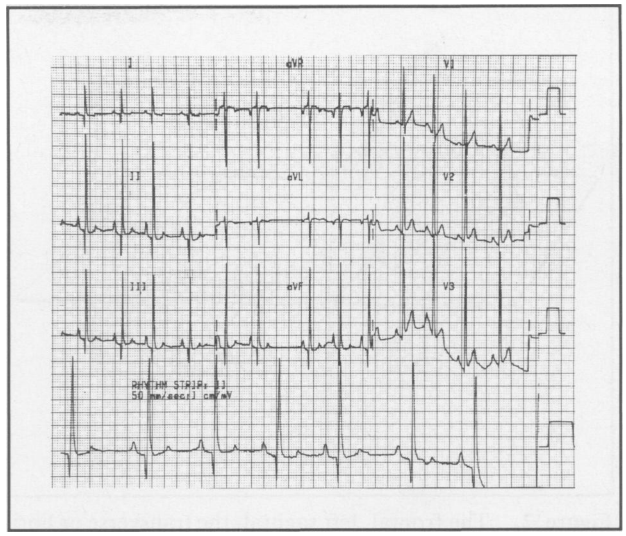

Figure 5. A nine-lead ECG was obtained from a two-year-old male Golden Retriever dog with a left basilar heart murmur (25 mm/sec, 1 cm = 1 mv). The bottom line is a lead II rhythm strip (50 mm/sec, 1 cm = 1 mv).
The P wave amplitude and duration in lead II are 0.3 mv (3 boxes) and 0.04 sec (2 boxes), respectively. Thus there is no evidence of atrial enlargement.
The R wave amplitude in lead II is 3.7 mv (37 boxes). The QRS duration in lead II is 0.07 sec (3.5 boxes). The MEA in the frontal plane is about 60°. These findings are typical of left ventricular enlargement.
There is no evidence of right ventricular enlargement; the MEA is not directed to the right heart, there is no S wave in leads I, II, and III, and there is no S wave in lead V_3.
This dog had subaortic stenosis with left ventricular enlargement.

larger than the left. Referring to Figure 3, with right heart enlargement the net direction of activation of the ventricles (MEA) would have to point toward the right ventricle (between 120° and −80°). Similarly it should be expected that in disorders characterized by left ventricular enlargement, the net direction of the wave of activation of the ventricles continues to point toward the left ventricle. Thus the MEA remains normal. In states which demonstrate a ventricular conduction abnormality, the MEA may be altered. In this situation the mean electrical axis is usually directed toward the region of the heart that contains the zone of conduction block (8).

The frontal plane leads are the common leads I, II, III, aVR, aVL, and aVF. Usually all of these leads must be examined to determine the MEA. It should be noted that there are several methods available to determine the MEA of the QRS complex in the frontal plane. All of these methods represent but an approximation of the true MEA. We present three common methods to calculate the MEA of the QRS complex in the frontal plane.

1. **The vector method.** Using leads I, II, or III and the frontal plane diagram, calculate the algebraic sum of the QRS deflections in any two of these leads (this does not include the T wave). Let us for example consider using the QRS complexes of leads I and III. Plot the algebraic sum of the deflections of the QRS complex in lead I along its axis on the frontal plane diagram. Similarly plot the algebraic sum of the QRS complex in lead III along its axis on the frontal plane diagram. From these two points identified on leads I and III, draw lines perpendicular to their respective axes. Note the point of intersection of these two perpendicular lines. A line drawn from the center of the heart (center of the frontal plane diagram) to this intersect describes the MEA.
2. **The isoelectric method.** Identify the frontal plane lead from the ECG whose QRS complex is isoelectric (algebraic sum of all deflections of the QRS approximately equals zero or is closest to zero; T waves are never included here). Next find the frontal plane lead that is perpendicular to this isoelectric lead using the frontal plane diagram. Note the net polarity of the complexes in this perpendicular lead. The polarity and direction of this perpendicular lead on the frontal plane diagram describe the MEA.

At times, no lead is close to isoelectric; if this occurs then the MEA may be difficult to calculate with this method. At other times most of the frontal plane leads are isoelectric; if this occurs the MEA in the frontal plane cannot be determined and suggests that the MEA is perpendicular to the frontal plane. We have frequently noted this last pattern particularly in deep-chested dogs, such as the Doberman Pinscher, that have a more vertical heart.

3. **The largest single deflection method.** Identify the frontal plane lead with the QRS complexes that contain the largest single deflection. Using the frontal plane diagram read the MEA angle as indicated by the axis of the lead identified and polarity along this axis by the polarity of this largest single deflection.

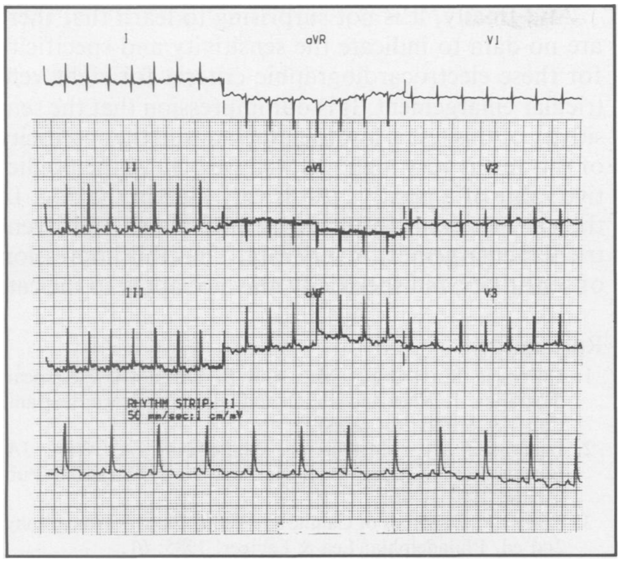

Figure 6. A nine-lead ECG was obtained from a four-year-old male domestic short-hair cat (25 mm/sec, 1 cm = 1 mv). The bottom line is a lead II rhythm strip (50 mm/sec, 1 cm = 1 mv).
The P wave amplitude and duration in lead II are 0.2 mv (2 boxes) and 0.03 sec (1.5 boxes), respectively. Thus there is no evidence of atrial enlargement.
The R wave amplitude in lead II is 1.7 mv (17 boxes). The QRS duration in lead II is 0.04 sec (2 boxes). The MEA of the QRS in the frontal plane is about 75°. These findings are typical of left ventricular enlargement.
This cat had dilated cardiomyopathy with left ventricular enlargement and left atrial enlargement.

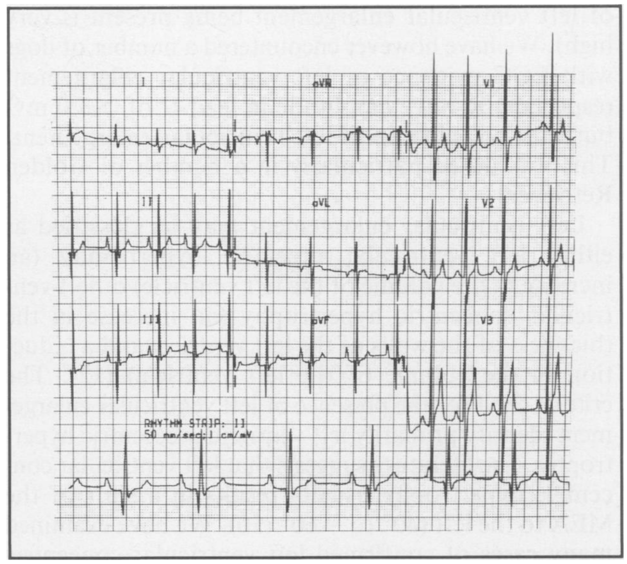

Figure 7. A nine-lead ECG was obtained from a six-month-old female Cocker Spaniel dog (25 mm/sec, 1 cm = 1 mv). The bottom line is a lead II rhythm strip (50 mm/sec, 1 cm = 1 mv).
The P wave amplitude and duration in lead II are 0.3 mv (3 boxes) and 0.04 sec (2 boxes), respectively. Thus there is no electrocardiographic evidence of atrial enlargement.
The R wave amplitude in lead II is 2.2 mv (22 boxes). The QRS duration in lead II is 0.08 sec (4 boxes). The MEA in the frontal plane is about 45°. Except for a slightly prolonged QRS duration, these findings are not typical of left ventricular enlargement.
There is an S wave in leads I, II and III; although the S wave in lead III is particularly small. As well there is a large S wave in V_3 (2.5 mv (25 boxes)). These two findings, particularly the presence of the deep S wave in lead V_3, provide strong evidence of right ventricular enlargement.
This dog had pulmonic stenosis with right ventricular and right atrial enlargement.

What is the significance of S waves in horizontal plane lead V_3?

Figure 2 illustrates the orientation of the horizontal plane. V_3 is a horizontal plane lead. The location of the V_3 electrode on the thorax is illustrated in Figure 4. In normal individuals the V_3 QRS complex is almost entirely positive. This lead is useful in detecting right ventricular enlargement. The presence of a deep S wave in V_3 provides strong evidence of right ventricular enlargement. The amplitude of the R wave in lead V_3 may also provide evidence of left ventricular enlargement (9).

Determination of left ventricular enlargement

The electrocardiographic criteria for left ventricular enlargement are:

1. **For the dog: (10) (Figure 5)**
   - **a) R waves that are too tall in lead II,**
     small dog (<20 kg): R > 2.5 mv
     large dog (>20 kg): R > 3.0 mv
   - **b) QRS duration that is excessive in lead II,**
     small dog (<20 kg): QRS > 0.05 sec
     large dog (>20 kg): QRS > 0.06 sec
     giant breeds: QRS > 0.065 sec
   - **c) ST segment depression,**
     0.2 mv or more
   - **d) MEA of the QRS complex is normal in the frontal plane.**

If all four criteria are present then there is strong evidence for the existence of left ventricular enlargement. Of all four criteria cited, the criterion of excessive amplitude of the R wave in lead II is the strongest single criterion. If the R wave amplitude is excessive, then there is strong evidence for the existence of left ventricular enlargement. If only criteria b), c), and d) are present, then there is only weak evidence for the existence of left ventricular enlargement. ST segment depression and prolongation of the QRS duration may exist in disorders other than left ventricular enlargement.

2. **For the cat: (11) (Figure 6)**
   - **a) R waves that are too tall in lead II,**
     R > 0.9 mv

This is the only electrocardiographic criterion for the presence of left ventricular enlargement in the cat.

Once again one should ask "What is the sensitivity and specificity for this test of left ventricular enlargement in dogs and cats?". These data are not yet available. It is our impression that the sensitivity of these criteria is low to moderate and the specificity is very high. Furthermore, we believe the predictive value of a positive test result is high (that is, if the criteria for left ventricular enlargement are met, the probability of left ventricular enlargement being present is very high). We have however encountered a number of dogs with ECG evidence of left ventricular enlargement (especially R wave amplitude in lead II of >3.0 mv) but with no evidence of left ventricular enlargement. This was noted particularly in a number of Golden Retrievers.

Left ventricular enlargement may be classified as either left ventricular eccentric hypertrophy (an increase in the volume of the left ventricle) or left ventricular concentric hypertrophy (an increase in the thickness of the walls of the left ventricle and a reduction in the volume of the left ventricle) (12). The criteria cited for the presence of left ventricular enlargement identify primarily left ventricular eccentric hypertrophy. The literature suggests that left ventricular concentric hypertrophy usually results in a shift of the MEA to the left (40° to −60° (10). We have examined many cases of confirmed left ventricular concentric hypertrophy in the dog, and a shift in the MEA to the left is profoundly rare in this species. Furthermore, the R wave amplitude is often normal. We have however noted an increase in the R wave amplitude in a number of cases of profound left ventricular concentric hypertrophy (Figure 5).

Determination of right ventricular enlargement

The electrocardiographic criteria for right ventricular enlargement are:

1. **For the dog: (13) (Figure 7)**
   The QRS is of normal duration or slightly prolonged *and* at least one of the following three criteria are present.
   a) Presence of S waves in leads I, II and III,
   b) Presence of an S wave in lead V_3
   $S > 0.7$ mv, or $S > R$
   c) MEA of the QRS complex in the frontal plane is shifted to the right; MEA = 100° to −80°

The presence of all three criteria, in the absence of a QRS that is of very prolonged duration, provides strong evidence for the existence of right ventricular enlargement. Even the presence of only one of these criteria provides good evidence for the existence of right ventricular enlargement.

Recall that the left ventricle is normally considerably larger than the right ventricle. To fulfil these criteria for right ventricular enlargement, the right ventricle must first increase in size such that it equals the left ventricle and then progress in size such that it becomes larger than the left ventricle. Thus the right ventricle may enlarge slightly but still remain smaller than the left ventricle. In this situation the criteria for right ventricular enlargement will not be fufilled.

2. **For the cat: (14)**
   a) the MEA of the QRS complex in the frontal plane shifted to the right; MEA = 160° to −80°.

And finally, it is not surprising to learn that there are no data to indicate the sensitivity and specificity for these electrocardiographic criteria for right ventricular enlargement. It is our impression that the sensitivity of this test is low to moderate and the specificity of this test is very high. As well we believe the predictive value of a positive test is very high in the dog. In the cat however the incidence of isolated right ventricular enlargement is very rare. Thus this impression of sensitivity and specificity may not apply to the cat.

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