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Diagnostic Accuracy of the Electrocardiogram for Detection of Atrial and Ventricular Overloads in Dogs

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ABSTRACT

Background**:** Analysis of the electrocardiogram may suggest atrial and ventricular overloads. However, it has a low sensitivity and specificity for diagnosis of cardiac chamber overload. The accuracy of electrocardiographic interpretation can be improve using new cut-offs for the duration and amplitude of the electrocardiographic waves. Our objective was to evaluate the use of the electrocardiogram in the diagnosis of atrial and ventricular overload, using echocardiography as the gold standard test for the diagnosis of atrioventricular overload. We aimed to define new cut-off values that would increase the sensitivity and specificity of the electrocardiogram for diagnosis of chamber overload in dogs.

Materials, Methods & Results**:** Eletrocardiogram records were obtained in 81 dogs divided into 3 groups: Group 1A (healthy dogs ≤ 10 kg); Group 1B (dogs ≤ 10 kg with mitral or tricuspid valve disease); Group 2 (dogs weighing between 10.1 and 20 kg) and Group 3 (dogs > 20.1 kg). Duration in milliseconds (ms) and amplitude in millivolts (mV) of P waves and QRS complexes, PR and QT segment, T wave amplitude and ST segment were evaluated in lead DII. Using leads I and III, the mean cardiac electrical axis in the frontal plane, expressed in degrees, was determined as the mean of three consecutive measurements. Values considered normal in Group 1A and 1B for the durantion of P wave was ≤ 45 ms and QRS duration ≤ 55 ms. In Group 2 the duration of P wave was ≤ 47 ms and QRS duration ≤ 61 ms. In Group 3 the duration of P wave was ≤ 50 ms and duration QRS ≤ 64 ms. These values (duration of P wave and QRS duration) were compared with echocardiographic measurements of the left atrium, considering the reference value AE/Ao ≤ 1.4 and measurements of the left ventricle in M-mode according to the body weight, respectively. A P wave amplitude ≤ 0.4 mV suggested that the right atrium size was normal and this was compared with the area of the right atrium measured on the echocardiogram. The right ventricle was assessed using the amplitude of S wave and right axis deviation and compared with the right ventricular area obtained by echocardiography. The reference value of the right atrium and right ventricle is according to the body weight. For both the right and left atria, there was concordance between the diagnoses with electrocardiography and echocardiography. For the right and left ventricle was no agreement between the diagnoses. All criteria examined had low sensitivities, usually with high specificities. But it was not possible to determine a new cut-off that would improve the sensitivity of the electrocardiogram for diagnosis of atrial and ventricular overload in dogs.

Discussion**:** The electrocardiogram analysis produced false interpretations for the measures indicative of atrioventricular overloads and should not be used alone, for diagnosis of cardiac chamber overload. The standard electrocardiographic reference values, for P wave duration and amplitude, were excellent for identification of normal atrial size. However, QRS duration, R wave amplitude (dependent of the dog's weight) and S wave amplitude, associated with cardiac electrical axis cannot be used for diagnosis of ventricle overload. Electrocardiographic analysis should not be used as a tool to assess cardiac chamber overload, which should be diagnosed by echocardiography and clinical investigation. Based on our findings echocardiogram is the gold standard test indicated to identify overload of cardiac chambers.

Keywords: electrocardiography, cardiac disease, ROC curve, arrhythmias, cardiac overload.

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INTRODUCTION

The electrocardiogram (ECG) measures the heart's electrical activity displayed in the form of specific waves representing the phases of depolarization and repolarization of the myocardium, with amplitude as a function of time [7,16]. The variability of electrocardiographic results in dogs is related to animal size, fat accumulation in obese animals and other diseases [20].

ECG analysis is fundamental in the diagnosis of cardiac arrhythmias and can also suggest atrial and ventricular overloads [13,25]. However, its sensitivity for the diagnosis of atrial and ventricular overloads is low [18]. It might be possible to improve the accuracy of ECG interpretation in veterinary medicine using new criteria and cut-offs for the duration and amplitude of the electrocardiographic waves, as demonstrated for the detection of left ventricular hypertrophy in man [14]. To date there have been few published studies in the veterinary literature, with reference values for ECG parameters in dogs with cardiac enlargement. In clinical settings, echocardiography is the gold standard test for the diagnosis of atrioventricular overloads in dogs. It offers the best analysis of the cardiac chambers, and assessment of atrial and ventricular dilatation and increased ventricular wall thickness [13,16,24].

Cut-off values can be defined to increase the sensitivity and specificity of ECG analysis, particularly standardization of reference values for ECG parameters in small, medium and large dogs. The objective of this study was to evaluate the accuracy of ECG analysis in the diagnosis of an enlarged heart, using echocardiographic examination as the gold standard measurement.

MATERIALS AND METHODS

Study design

The study was conducted with 81 dogs of different breeds, between 1 and 18 years of age. The animals were divided into 3 groups: Group 1A (healthy dogs weighing ≤ 10 kg); Group 1B (dogs with a body weight of ≤ 10 kg with myxomatous mitral or tricuspid valve disease); Group 2 (dogs weighing between 10.1 and 20 kg) and Group 3 (dogs > 20.1 kg).

Electrocardiography

Electrocardiographic records were obtained for 3 min using an electrocardiography device (TEB)[1]. The animals were positioned in right lateral recumbency and the electrodes were positioned as shown in Figure 1. ECG traces were obtained simultaneously in the bipolar leads DI, DII, DIII, and in the unipolar aVR, aVL and aVF and precordial or chest leads rV2, V2, V4 and V10. Duration in milliseconds (ms) and amplitude in millivolts (mV) of P waves and QRS complexes, PR and QT segment, T wave amplitude and ST segment were evaluated in lead DII (Figure 2). Using leads I and III, the mean cardiac electrical axis in the frontal plane, expressed in degrees, was determined as the mean of three consecutive measurements. The other leads were evaluated and the reference intervals for the electrocardiographic measurements, as well as the technique for performing the test, were as described in Tilley [20], except for the P wave duration variables and QRS complexes (Table1), which were according to the study of Wolf *et al*. [25].

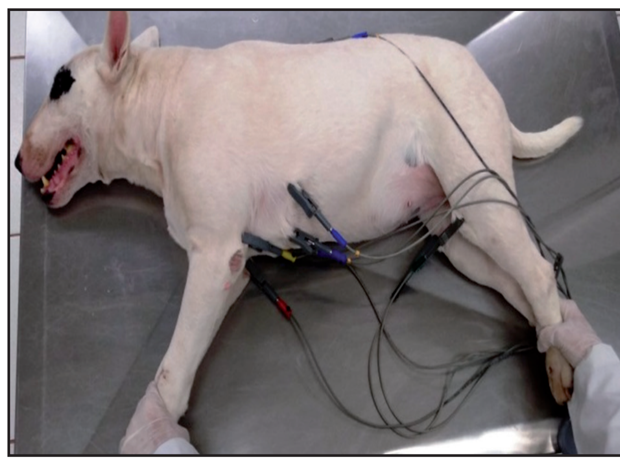

Figure 1. Female Bull Terrier, weighing 19 kg, in right lateral recumbency during electrocardiography. The position of electrodes on the body is standardized: yellow electrode in left foreleg, red electrode on right foreleg, green electrode on left hind leg and black electrode in right hind leg. Precordial or Chest leads: V1 (rV2) in the 5th intercostal space, near the right side of the sternum, V2 in the 6th intercostal space, near the left side of the sternum, V4 in the 6th intercostal space, in the left costochondral junction and V10 on the 7th dorsal spinous process.

Figure 2. Electrocardiographic tracing demonstrating the measurements of duration of P, PR, QRS and QT waves in lead D2.

Table 1. Electrocardiographic values suggestive of overload in the left atrium, right atrium, left ventricle and right ventricle.

	Electrocardiographic values of overload used in this study
Left atrium P wave (ms)	Group 1A e Group 1B: P > 45 ms in D2 Group 2: P > 47 ms in D2 Group 3: P > 50 ms in D2
Right atrium P wave (mV)	All Groups: *P* > 0.4 mV in D2
Left Ventricle	Group 1A e 1B: QRS > 55ms, R wave > 2.5mV in D2 and left axis deviation Group 2: QRS > 61ms, R wave >2.5mV in D2 and left axis deviation Group 3: QRS > 64ms, R wave > 3.0 mV in D2 and left axis deviation
Right Ventricle	All Groups: Right axis deviation or S wave > 0.8 mV in V2 and S wave > 0.35 mV in D2

Echocardiography

Echocardiography was performed with the ultrasound device Sonosite M-Turbo[2] and multifrequency sector transducer in all dogs. Qualitative assessment of the heart was performed in the two-dimensional (B-mode), which provides information on movement, cardiac anatomy and spatial relationship. B-mode imaging also served as a guide for M-mode and planimetry images, through which quantitative analysis was performed in systole and diastole from the cardiac chambers using frame rate. Color flow mapping and Doppler evaluation of large vessels was performed, for direct analysis of blood flow and identification of changes in the exam [9].

The images from the four chambers and left ventricle outflow tract were obtained from the right parasternal view in the longitudinal axis. In the transverse axis, at the level of the papillary muscles in M mode, measurements of the thickness of the interventricular septum, free wall of the left ventricle and internal diameter of the left ventricle were obtained. At the transaortic level, the relation between the left atrium and the aorta (AE/Ao) was obtained by the Swedish method [2], considering the reference value AE/Ao=1.4 (Figure 3).

From the left parasternal view, the images were analyzed on the longitudinal axis from the apical four and five chamber views. From the apical four chambers, the maximal area of the right atrium was calculated by tracing the endocardial border in the frame immediately after the opening of the tricuspid valve, disregarding the caudal vena cava region. The right ventricular planimetry was obtained in diastole by tracing the endocardial border at its greatest dimension, at the end of the diastole, immediately before the tricuspid valve closure, and in its smallest dimension, at the end of systole, in the frame after the opening of the tricuspid valve. Simpson's method was used to calculate left ventricular volume in systole and diastole, manually tracing the endocardial border, disregarding papillary muscles [6,22,23], and automatically calculated (Sonosite M-turbo)[2] [Figure 4].

Optimization of the images of the right atrium and ventricle was performed separately when they could not be obtained simultaneously. The average of three consecutive measurements was used according to the criteria of the Ultrasound Committee of the American College of Veterinary Internal Medicine [1,21]. The echocardiographic reference intervals used in this study are described by Boon [2] for the left atrium and left ventricle, while the right ventricle and right atrium followed that proposed in Gentile-Solomon & Abbott [10].

Statistical analysis

All statistical analysis were done with SPSS software[3]. The Kappa concordance index was evaluated to assess how the 2 methods of assessment agreed on the diagnosis. A k of 0 indicates "no agreement" beyond that expected on the basis of chance alone, whereas a k of 1 indicates "perfect agreement." Intermediate values of k indicate "poor agreement" ($k \leq 0.20$), "fair agreement" ($0.21 \leq k \leq 0.40$), "moderate agreement" ($0.41 \leq k \leq 0.60$), "substantial agreement" ($0.61 \leq k < 0.80$), and "good agreement" ($0.81 \leq k < 1.0$).

A new cut-off for the variables was set, adjusting the logistic model from the regression analysis, using Wald Test and Hosmer and Lemeshow test. Sensitivity (Se) and specificity (Sp) of the protocol were evaluated by the chi-squared test and ROC curves to evaluate the performance of the electrocardiogram. For all tests the significance level was set at 5% ($P < 0.05$).

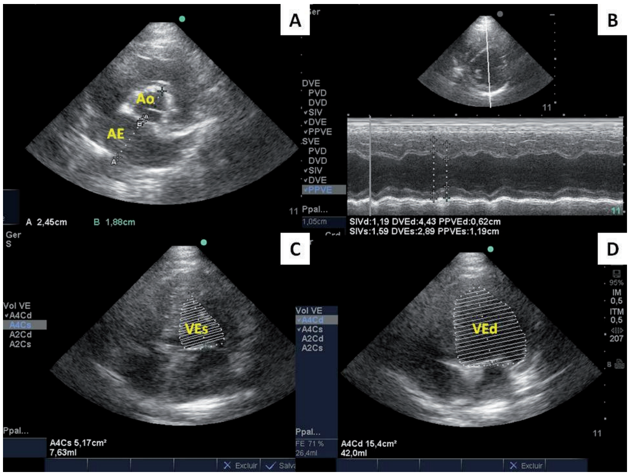

Figure 3. In the upper part, two-dimensional and M-mode Doppler echocardiographic images obtained from the right parasternal window. At the bottom of the figure, two-dimensional images of the four-chamber longitudinal image, obtained from the left parasternal window. A- Cross section, level of the aortic valve, showing aorta (Ao) and left atrium (AE). B- Transverse axis, chordal level, showing left ventricle, interventricular septum in systole and diastole (SIVs and SIVd), internal diameter of the left ventricle in systole and diastole (DIVEs and DIVEd) and left ventricular free wall in systole and diastole (PLVEs and PLVEd). C & D- Simpson's method in the left ventricle in systole (C) and diastole (D).

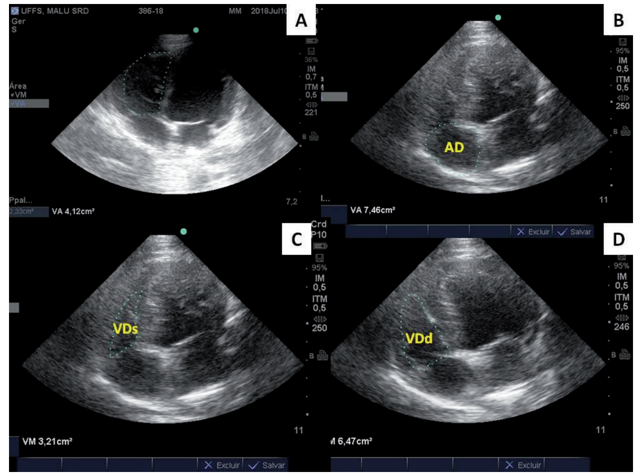

Figure 4. Two-dimensional echodopplercardiographic images of the longitudinal section, apical four chamber view, obtained from the left parasternal window. A- Apical four chambers optimized for the right side demonstrating RV planimetry in diastole. B- Apical four chambers showing the maximum area of RA. C & D- Apical four chambers showing RV planimetry in systole (C) and diastole (D).

RESULTS

Ninety-one adult dogs were evaluated. Of these, ten dogs were excluded due to obesity, right bundle branch block, diaphragmatic hernia and cardiac tumor. Of the 81 dogs evaluated in this study, 33 dogs were classified as Group 1A, 31 dogs as Group 1B, 6 dogs as Group 2 and 11 dogs as Group 3. Due to the large individual differences, it was not possible to perform statistical comparison between groups. For both the right and left atria, there was concordance between the diagnoses with electrocardiography and echocardiography.

For the right atrium κ = 0.300 and *P* -value = 0.012 and for the left atrium κ = 0.245, *P* -value = 0.043. For the diagnosis of right atrium enlargement using the electrocardiogram and setting a cut-off for amplitude of P wave as 0.4 mV, Se = 0.23 and Sp = 0.99. Suggesting 99% accuracy for diagnosis of normal atrial size. However only 23% of animals with right atrial changes were identified (Table 2).

For the diagnosis of left atrium enlargement using the electrocardiogram and a cut-off for P wave duration > 45 ms for dogs with a body weight of 10 kg or less, P > 47ms for dogs weighing between 10.1 and 20 kg and P > 50 ms in dogs weighing > 20.1 kg, Se = 0.385 and Sp = 0.868. That is, the alternative protocol was excellent for identification of healthy animals, (identifying correctly in 86.8% of cases) but very poor for identification of the dogs with left atrium overload, (identifying only 38.5% of these) [Table 3].

For the right ventricle, we found Se = 0.125 and Sp = 0.910 using the right axis deviation or S wave > 0.8 mV in V2 and S wave > 0.35 mV in D2. Although there was no agreement between the diagnoses with κ = 0.135 and *P*-value = 0.271. There was no agreement between the two methods (ECG and echocardiogram) for assessment of the right ventricle. Sensitivity was low. Using the ECG it was not possible to assess whether the right ventricle was normal (healthy) or enlarged (overload) or whether there was remodeling of the right ventricle.

For the left ventricle, even though we found, Se = 0.263 and Sp = 0.837, there was no concordance between the diagnoses (κ = 0.104 and *P*-value = 0.289). There was no agreement for the two methods for assessment of left ventricular size. Sensitivity was low and specificity moderate. Echocardiography was needed for assessment of left ventricular size.

All criteria examined had low sensitivities, usually with high specificities. And it was not possible to determine a new cut-off that would improve the sensitivity of the electrocardiogram for diagnosis of atrial and ventricular overload in dogs. When we adjusted the logistic model, the probability of that animal having increased size of the cardiac chamber in question increased. If it were possible to find an ideal cut-off, we would find a scenario where a minimum value of P wave amplitude, for example, would have a high probability of that animal having right atrium overload. Therefore, the diagnosis of cardiac overload using electrocardiography does not have a cut-off that is better than the electrocardiographic reference values previously published.

Table 2. Contingency table for chi-squared test comparing the alternative protocol (electrocardiography = ECG) with echocardiography for right atrium enlargement.

		Echocardiography		Total
		Negative	Positive	
ECG	Negative	67	10	77
	Positive	1	3	4
Total		68	13	81

Table 3. Contingency table for chi-squared test comparing the alternative protocol (electrocardiography = ECG) with the Gold Test (echocardiography) for left atrium enlargement.

		Echocardiography		Total
		Negative	Positive	
ECG	Negative	59	8	67
	Positive	9	5	14
Total		68	13	81

DISCUSSION

The electrocardiogram is widely used in routine small animal practice for pre-anesthetic evaluation, to investigate the presence of arrhythmias and to monitor disease in the cardiopathic patient. Because ECGs are easy and quick to perform, their use has become very widespread. However, the ECG should be interpreted in conjunction with findings of other tests indicative of atrioventricular overload, such as echocardiogram and chest radiography that suggests enlargement of the cardiac silhouette or pulmonary congestion and large vessels [7,13].

The results of this study suggest that electrocardiographic criteria for evaluation of atrial and ventricular overload are similar to those reported by Schober *et al*. [18], who found accuracy of the ECG for detecting left atrial overload, which resulted in relative specificity and low sensitivity in cats with cardiomyopathy. Another recent study showed good specificity in the detection of ventricular hypertrophy in cats and low sensitivity, with a large number of false negative animals [17]. However, in human patients the ECG is considered a screening test for the detection of atrioventricular overloads and a sensitive indicator of heart disease [11,15]. There are few published veterinary studies that are directly comparable to this one.

Echocardiography is the gold standard test indicated to identify overload of cardiac chambers, myocardial lesions and valvular lesions. However, the cardiac chambers are a three-dimensional structure with complex geometry, and because enlargement may occur non-uniformly in a number of directions, uniplanar assessment of cardiac chamber size may be unreliable. Cardiac chamber volume obtained by 2D echocardiography offers limited accuracy and real-time three-dimensional echocardiography, computed tomography and magnetic resonance are non-invasive, accurate and feasible methods with superior accuracy to two-dimensional methods [5,19]. Echocardiography does not replace the full clinical investigation, but rather should be used in conjunction with the physical examination and heart auscultation for the diagnosis or management of the patient [12]. For accurate diagnosis echocardiography must be performed by a professional with experience in the technique, knowledge of cardiac alterations, hemodynamics, peculiarities of the different breeds of dogs and also understanding about the limitations of this study.

Adjustments of position and transducer angulation and imaging plane orientations were necessary in most animals in this study to obtain an optimal image, especially in the images for evaluation of right atrium and right ventricle. Two dogs evaluated in this study had atrial and right ventricular overload evaluated by two-dimensional echocardiographic with signs of right congestive heart failure. However, there was no increase in the reference values for right ventricular planimetry in systole or diastole in these cases, making them false negatives for right ventricular overload. Of these, only one had an increase in the right atrial echocardiographic measurement and the other one was also considered false negative for right atrial overload. There are few studies that propose numerical reference values for the atrium and right ventricle, and it is suggested that more studies are needed to define the reference values with greater confidence for the right side [10]. The agreement with a reference standard is an essential component for the evaluation of any modality [10,19].

Based on our findings, many of the echocardiographic measurements have individual variations in the patient, up to 10% or more, depending on the technique performed by the operator. There were also variations between observers, especially the measurements of planimetry and the short axis of the left ventricle [3,13]. In this study echocardiography was performed by a single trained operator, so it was not possible to assess inter-operator and intra-operator coefficient was not evaluated. However, the ability to consistently replicate images as a single observer and between observers is vital for clinical application, particularly for the individualized longitudinal monitoring of the patient and their design and analysis of clinical studies [8].

Another analysis that may be ambiguous in echocardiography is color flow assessment because doppler technology is so sensitive that the blood flow associated with the normal closure of a valve can be mistaken for regurgitation. Therefore, the clinician should be cautious in interpreting echocardiographic findings that are inconsistent with clinical findings or other imaging tests and a second opinion from a cardiologist is often required [3,13].

Myxomatous mitral valve disease is the most common cardiovascular disease in the dog. Progressive degenerative lesions of the valve result in mitral regurgitation imposing a gradually increasing chronic volume load on the left side of the heart resulting in clinically detectable enlargement of the left side of the heart [4]. In this study almost half of the dogs weighing < 10 kg, had myxomatous mitral or tricuspid valve disease, but it was not possible to compare statistically the groups 1A and 1B due to the small number of true positive animals, demonstrating once again the low sensitivity of ECG for dogs with cardiac abnormality.

CONCLUSION

All criteria examined had low sensitivities with high specificity and the diagnosis of cardiac overload using electrocardiography does not have a cut-off that is better than the electrocardiographic reference values previously published.

In conclusion, the electrocardiogram analysis produced false interpretations for the measures indicative of atrioventricular overloads and should not be used for diagnosis of cardiac chamber overload.

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Ethical approval. All methodology employed obeyed the precepts of the UFFS Ethics Committee on Animal Use (CEUA / UFFS) and received prior approval, with protocol number 23205.001465/2018-14.

Declaration of interest. The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article

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