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Electrocardiographic characterization of the p wave and determination of the mean atrial electrical axis in dogs with atrial remodeling

Caracterização eletrocardiográfica da onda p e determinação do eixo elétrico atrial médio em cães com remodelamento atrial

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Highlights

Mean atrial electrical axis (AEA) does not differ in dogs with left atrial remodeling.
Mean AEA does not reflect alterations in atrial overload.
Mean AEA does not reflect changes in interatrial conduction disorders.
Mean AEA is a poorly studied metric.
It is interesting to investigate whether this atrial measurement can be relevant.

Abstract

Due to potential alterations in atrial depolarization vectors in canine heart disease, the atrial electrical axis (AEA) may appear altered in patients with atrial remodeling (AR). The aim of this study was to analyze the AEA and P-wave duration in the electrocardiogram of three groups of dogs: healthy patients, cardiac patients without left AR, and cardiac patients with left AR. Of the 56 evaluated dogs, nine were healthy, 27 were cardiac patients without left AR, and 20 were cardiac patients with left AR. The classification of myxomatous mitral valve disease includes stage A, comprising dogs at high risk of developing the condition; stage B, which includes asymptomatic dogs subdivided into B1, with mitral valve regurgitation not yet causing cardiac remodeling, and B2, with sufficient mitral valve regurgitation to cause cardiac remodeling, where treatment is indicated even in the absence of clinical signs; stage C, covering symptomatic dogs; and stage D, including dogs refractory to treatment. Therefore, 27 dogs were in stage B1, two in B2, 15 in C, and three in D. The P-wave duration in the remodeling group (53

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milliseconds (ms)) was higher (p=0.0088) than in the group without left AR (46 ms). The P-wave duration in healthy dogs did not differ from that of dogs with and without remodeling. The AEA in healthy animals (43.65±19.79º) was lower (p=0.0015) than in the groups with and without left AR (69.58±18.00º and 63.40±15.89º). Animals without remodeling did not differ from those with remodeling, and despite the difference found in healthy animals, the values were within the normal range for the species, and no cardiac dogs exhibited a deviation of the AEA. Stage D dogs had longer P-wave durations than healthy and stage B1 dogs and did not differ from stage B2 and C groups (p=0.0269). Healthy dogs did not differ from stage B2, C, or D dogs in recording the AEA, only being lower than the B1 dogs (p=0.0120). The AEA and P wave duration are parameters that should not be used to define left AR in dogs with heart disease.
Key words: Atrial depolarization. Atrial overload. Atrial vector. Electrocardiogram.

Resumo

Em virtude de prováveis alterações vetoriais de despolarização atrial em cães cardiopatas, o eixo elétrico atrial (EEA) pode se alterar em pacientes com remodelamento atrial (RA). O objetivo foi analisar o EEA e a duração da onda P no eletrocardiograma de três grupos de cães: hígidos, cardiopatas sem e com RA esquerdo. Dos 56 cães avaliados, nove foram hígidos, 27 cardiopatas sem e 20 cardiopatas com RA esquerdo. Quanto a doença mixomatosa de valva mitral a classificação inclui os estágios A, sendo cães com alto risco de desenvolver a afecção, B, compreendendo cães assintomáticos – subdivido em B1, com regurgitação de valva mitral ainda incapaz de causar remodelamento cardíaco, e B2, com regurgitação de valva mitral suficiente para causar remodelamento cardíaco, havendo indicação de tratamento ainda na ausência de sinais clínicos – C, abrangendo cães sintomáticos, e D, incluindo os cães refratários ao tratamento. Sendo assim, os cardiopatas foram estratificados em 27 cães foram B1, dois cães B2, 15 cães C e três cães D. A duração da onda P no grupo com remodelamento (53 milissegundos (ms)) foi superior (p= 0,0088) ao grupo sem RA (46ms). A duração da onda P dos cães hígidos não diferiu dos cães com e sem remodelamento. O EEA dos animais hígidos (43,7±19,8º) foi inferior (p=0,0015) aos grupos com e sem RA esquerdo (69,6±18,00 e 63,4±15,9º). Animais sem remodelamento não diferiram de animais com e, apesar da diferença encontrada em animais hígidos, os valores encontram-se dentro da normalidade para a espécie e nenhum cão cardiopata apresentou EEA desviado. Os cães em estágio D apresentaram durações de onda P superiores aos grupos de cães hígidos e B1 (p=0,0269), porém não diferiram dos grupos B2 e C. Os cães hígidos não diferiram dos cães B2, C e D quanto ao eixo, sendo apenas inferiores aos valores de eixo dos cães em estágio B1 (p=0,0120). O EEA médio e a duração de onda P são parâmetros que não devem ser utilizados para definir RA esquerda em cães cardiopatas.
Palavras-chave: Despolarização atrial. Eletrocardiograma. Sobrecarga atrial. Vetor médio atrial.

Introduction

Atrial remodeling (AR) occurs due to structural and functional changes in myocytes and is commonly observed in dogs with myxomatous valve disease. Atrial remodeling makes the myocardium more susceptible to ectopic beats (Nattel et al., 2008), which can be determined using an electrocardiogram (ECG). In addition to detecting cardiac arrhythmias and myocardial conduction disorders, the ECG can indicate cardiac chamber overload and determine the mean depolarization vector, characterized by the mean electrical axis (MEA) (Santilli et al., 2018b).

The MEA determines the general direction of the myocardium's electrical conductivity during depolarization, resulting from the sum of multiple instantaneous vectors from the cardiac cycle. Based on the anatomical plane, the MEA can be atrial or ventricular. The Bailey Hexaxial System, which combines bipolar and unipolar leads, is used to define the frontal plane MEA, with normal values for dogs ranging from -18° to +90° (Nattel et al., 2008; Santilli et al., 2018a).

Considering the potential of electrocardiographic examination in the stratification and definition of AR in dogs with heart disease, it is important to develop a detailed analysis of the P wave, particularly in relation to its MEA. The objective of this study was to determine the duration of the P wave and its MEA in healthy dogs, as well as in dogs with and without heart disease and left atrial remodeling, to assess its applicability in distinguishing atrial remodeling in dogs with degenerative mitral valve disease.

Materials and Methods

Animals and group formation

After approval by the Animal Use Ethics Committee (CEUA) under number 6268070223, electrocardiographic and echocardiographic parameters of 56 dogs treated between April 2022 and August 2023 were evaluated. The animals were divided into three groups: Group 1 - adult, healthy dogs; Group 2 - dogs with valve disease without left atrial remodeling; and Group 3 - dogs with valve disease with left atrial remodeling. The inclusion criteria were adult dogs with degenerative myxomatous valve disease diagnosed by echocardiography. Exclusion criteria included dogs with previous diagnoses of severe respiratory dysfunction, obese dogs, and young animals (under one year of age).

Based on the patients' medical records and echocardiographic examinations, the 56 animals were stratified as healthy, asymptomatic, and symptomatic heart disease patients. Additionally, the data obtained from echocardiographic examinations allowed the classification of asymptomatic dogs with evidence of atrial and ventricular remodeling. Dogs that were from predisposed breeds or had a family history of heart disease were classified as A.

Asymptomatic dogs with mild hemodynamic alterations were classified as B1. Asymptomatic dogs with a left atrium to aortic ratio (LA/Ao) greater than 1.6 cm and weight-normalized left ventricular end diastolic diameter (LVIDD) measurements greater than 1.7 cm were classified as B2. Symptomatic dogs (showing cough, tachypnea, respiratory distress, or restlessness) without refractory signs were allocated to Group C, while those with refractory signs to therapy applied in higher doses, such as pulmonary edema, dyspnea, syncope, and cavitary effusions, were classified as D. Furthermore, based on this classification, it was possible to define patients with heart disease who did or did not have atrial remodeling. The group of heart disease patients without atrial remodeling included those classified as A and B1, while the group with AR included those classified as B2, C, and D.

Electrocardiography and echocardiography

The ECG, performed using the InCardio electrocardiograph (InPulse®), was conducted in a quiet room with the dog positioned in right lateral recumbency, without the use of chemical restraint. Electrodes were placed as follows: on the thoracic limbs, the red electrode was positioned on the right limb at the shoulder joint, and the yellow electrode was placed on the left limb at the same location. For the pelvic limbs, the black electrode was positioned on the right limb at the knee joint, and the green electrode was placed on the left limb at the knee joint. Bipolar leads (lead I, lead II, lead III) and augmented unipolar leads (aVR – right arm, aVL – left arm, aVF – left foot) were recorded. Electrodes were also positioned for precordial leads based on the modified Wilson System: lead V1 was placed in the right first intercostal space (ICS); the remaining leads were placed in the left sixth ICS, with V2 at the sternocostal junction; V3 between V2 and V4; V4 at the costochondral junction; V5 between V4 and V6; and V6 slightly dorsal to V5. Afterwards, 70% isopropyl alcohol was applied to each contact point (Santilli et al., 2018a).

With the dog placed in right lateral recumbency, an echocardiographic examination was performed using a Sonosite M-turbo®. The LA/Ao ratio was measured at the start of diastole in the right parasternal short axis (Madron, 2016). The left ventricular end-diastolic diameter (LVIDd) during diastole was assessed using the M-mode of the left ventricle and normalized by weight, to functionally classify dogs and stratify them into stages B1, B2, C, and D (Keene et al., 2019).

Statistical analysis

The data obtained were analyzed using GraphPad Prism 5.0® software. The groups underwent the Shapiro-Wilk normality test, with parametric variables described as mean values ± standard deviations and non-parametric variables as medians (interquartile ranges). The dogs in the healthy group were compared with those without and with cardiac remodeling. Subsequently, healthy dogs and dogs in different stages of heart failure (B1, B2, C, and D) were compared. The ANOVA test and Tukey's post-test or the Kruskal-Wallis test and Mann-Whitney's post-test were used to determine differences between the mean and median values among the groups described.

Additionally, atrial MEA values were correlated with P wave duration and the LA/Ao ratio using Spearman's correlation test, considering $p < 0.05$.

Results and Discussion

Of the 56 dogs, nine were healthy, 27 had heart disease without left AR, and 20 had heart disease with left AR. The mean ages were 10.4, 10.2, and 11.9 years in the respective groups. Additionally, there was a predominance of sinus arrhythmia in the healthy animals and in the cardiac patients without remodeling, while those with atrial remodeling exhibited predominantly sinus tachycardia. Moreover, the animals were stratified as 27 dogs in stage B1, two in B2, 15 in C, and three in D, with no dogs classified as A.

Table 1 illustrates the values of the left atrium/aorta ratio, P wave duration in milliseconds (ms), and mean atrial electrical axis in degrees for healthy dogs and those with and without significant atrial remodeling. Regarding the left atrium-to-aorta ratio, it was established that the degree of remodeling in dogs with heart disease and an LA/Ao ratio <1.6 was not significant, as the group without remodeling did not differ from healthy animals. Dogs with left AR, stratified by an LA/Ao ratio >1.6, showed greater atrial enlargement compared to healthy dogs without remodeling.

Table 1

Mean values ± standard deviation or medians (interquartile ranges) of the left atrium-to-aorta ratio, duration of the P wave in milliseconds, and mean atrial electrical axis in degrees for groups classified as healthy, cardiopathic without significant remodeling (LA/Ao<1.6), and cardiopathic with significant atrial remodeling (LA/Ao>1.6)

	Healthy	Without remodeling	With remodeling	p-value
LA/Ao	1.2 ± 0.1^{a}	$1.4(1.1-1.5)^{a}$	2.0 ± 0.3^{b}	<0.0001
P (ms)	47.9 ± 13.7^{ab}	$46.0(40.0-52.0)^{a}$	$53.0(48.5-58.0)^{b}$	0.0088
Mean AEA (º)	43.7 ± 19.8^{a}	69.5 ± 18.0^{b}	63.4 ± 15.9^{b}	0.0015

Superscripted lowercase letters in the row represent statistical differences according to ANOVA - Tukey or Kruskal-Wallis-Mann-Whitney tests, considering p<0.05. Left atrium-to-aorta ratio (LA/Ao); atrial electrical axis (AEA); milliseconds (ms).

In terms of P wave duration, the groups without remodeling and with significant remodeling showed differences. It was observed that the P wave duration in dogs with remodeling was greater than in those without remodeling. However, healthy dogs did not differ from dogs with and without remodeling.

Analyzing the atrial MEA, it was found that dogs with heart disease had higher electrical axis values compared to the group of healthy animals. The healthy dogs had an electrical axis with an approximate average difference of 20-26 degrees to the left.

Table 2 demonstrates the values for the ratio of the left atrium to the aorta, the duration of the P wave in ms, and the mean electrical axis of the P wave in degrees in healthy dogs and those with heart disease, functionally classified as asymptomatic without significant remodeling (B1), asymptomatic with significant remodeling (B2), symptomatic (C), and with refractory congestive heart failure (CHF) (D).

Table 2
Mean values ± standard deviation or median (interquartile ranges) of the echocardiographic ratio between the left atrium and aorta, electrocardiographic duration of the P wave, and mean atrial electrical axis for groups classified as healthy and with valvular disease B1, B2, C, and D

	LA/Ao	P (ms)	Mean AEA (º)
Healthy	1.2±0.1[a]	47.9±13.7[ab]	43.7±19.8[a]
B1	1.3(12-1.5)[a]	46.0(40.0-52.0)[a]	69.6±18.0[b]
B2	1.7(1.6-1.8)[a]	50.0(46.0-57.0)[ab]	59.5±0.7[ab]
C	1.9±0.3[b]	52.0(48.0-93.0)[ab]	63.6± 18.4[ab]
D	2.2(2.2-2.4)[b]	58.0(58.0-58.0)[b]	65.2±0.0[ab]
p-value	<0.001	0.0269	0.0120

Superscripted lowercase letters in the columns represent statistical differences according to ANOVA - Tukey or Kruskal-Wallis-Mann-Whitney tests, considering $p<0.05$. Left atrium-to-aorta ratio (LA/Ao); atrial electrical axis (AEA); milliseconds (ms).

Considering the healthy and heart-diseased animals with and without significant left AR, the values for the LA/Ao ratio increased progressively. It can be noted that the more advanced stages of mitral valve disease (C and D) were distinct from those of the groups of healthy dogs, B1, and B2.

Group B1 differs from group D with higher P wave duration values detected only in refractory animals. Healthy dogs did not differ from asymptomatic cardiac patients without significant cardiac remodeling (B1), patients with cardiac remodeling (B2), or non-refractory symptomatic dogs (C).

Regarding atrial MEA, a difference was observed between healthy dogs and those with heart disease without significant AR (B1). The variation in the axis among animals classified with mitral valve disease ranged from approximately 59 to 69 degrees. Of the 56 animals, 5.4% exhibited a rightward deviation of the atrial MEA, including two classified as B1 and one as B2. No cases of leftward deviation of the atrial electrical axis were observed, even in dogs with significant AR or in more advanced stages of heart disease.

Additionally, 76.8% of the dogs showed an increase in P wave duration, compared to the reference value of 40 ms. Considering the sample, 55.6% of the healthy dogs had increased P wave duration, as did 70.4% of the B1 dogs and 100% of the B2, C, and D groups. Furthermore, there was no correlation between atrial MEA and P wave duration (p=0.5612), or the LA/Ao ratio (p=0.4937).

Left AR is a progressive disorder in which regurgitation occurs due to valve degeneration. The resultant volume overload leads to remodeling (Dillon et al., 2012; Hansson et al., 2002). In agreement with this, the analysis between groups showed a difference between the dogs with heart disease that have AR compared to other groups.

Corroborating with findings from Ogawa et al. (2022) and Na et al. (2008), who analyzed P wave formation on the ECG at different stages of CHF, it was found that P wave duration (ms) exhibited a statistical difference. In this study, only the animals classified as B1 differed from those in stages B2, C, and D. These groups did not differ from each other. There was also no difference between the healthy animals and those with heart disease.

Furthermore, asymptomatic animals with heart disease did not differ from symptomatic ones. Although the duration of the P wave suggests left atrial overload, the discriminatory accuracy of this measure on the ECG is still insufficient (Ogawa et al., 2022; Tilley & Smith, 2001).

The analysis between healthy dogs and dogs with mitral valve degenerative disease, conducted by Soto-Bustos et al. (2017), suggests that the ECG can serve as the first phase in identifying remodeling. The same study indicates that the duration of the P wave does not enhance the diagnostic capacity of the ECG against AR. The weak accuracy of the ECG is also notable, given the presence of healthy false-positive dogs in this analysis.

Studies on ventricular MEA in dogs are extensive in the literature. According to Brojbă (2018), the ventricular vector shows deviations, which can be to the right, representing an increase on the right side of the heart, or to the left, indicating an increase on the same side of the myocardium. In the present study, the healthy animals showed mean atrial axis deviations to the right and were lower when compared to B1, but there was no difference in relation to B2, C, and D dogs.

The increase in the right atrium may counterbalance an increase in the left atrium, which justifies the axis shift to the left in dogs with heart disease, and may be a limitation of this study suggested by the authors. The lack of correlation between atrial MEA and P-wave duration shows that an increase in one parameter does not lead to a proportional increase in the other. Similarly, the LA/Ao ratio and atrial MEA were not correlated, indicating that a higher AR does not consistently characterize the axis.

In general, the duration of the P wave is the only criterion that reflects the greater severity resulting from the progressive enlargement of the left atrium. Moreover, there was no deviation of the axis to the left in dogs with AR. The mean cardiac axis is equivalent to the magnitude and net direction of cardiac electrical conduction. One possibility for deviations in the axis could be the need for a greater number of vectors, i.e., a greater number of cardiomyocytes depolarizing in the same direction (Kuhn & Rose, 2008).

Due to the high prevalence of mitral valve disease, a study with a larger sample of dogs, mainly healthy animals, B2, and D is suggested to obtain more accurate results.

Conclusion

The mean atrial electrical axis, even when within physiological values, cannot serve as a parameter to rule out the presence of left atrial remodeling. P wave duration has low sensitivity for characterizing left overload in dogs with valve disease. The mean atrial electrical axis and P wave duration in dogs with heart disease are parameters that should be analyzed with caution and are not applicable to discriminate atrial remodeling in dogs with degenerative mitral valve disease.

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