# Use of computed radiology as a screening test for the identification of congenital heart disease in dogs

# Utilização da radiologia computadorizada como exame de triagem na identificação de cardiopatias congênitas em cães

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**Highlights:**
The radiological examination was able to identify the healthy individual.
It was not possible to differentiate the forms of heart disease.
The more specific the diagnosis the less likely this technique is to be correct.
This technique should not be used as a sole screening method.

## Abstract

The objectives of this study were to evaluate the accuracy of thoracic radiology as a screening test for congenital heart diseases in dogs, to identify the main contributions and limitations of this modality, and to verify the reproducibility of the evaluations by three observers with different levels of training. An interobserver, observational, retrospective and prospective study was carried out, including ninety dogs: thirty healthy animals, thirty with acquired heart diseases and thirty with congenital heart diseases, which all had thoracic radiographs and a confirmed echocardiographic diagnosis. The cases were separated and randomized by a mediator who did not participate in the reading of the radiographic examinations, and no evaluator had access to the patients' data. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and accuracy of each observer were calculated in relation to the correct classification of dogs to groups of normal or acquired and congenital heart diseases, as well as identification of enlargement of the cardiac silhouette and large vessels of dogs with congenital heart diseases. Finally, the Kappa coefficient was obtained between the observers to verify the reproducibility of the radiological evaluations performed. In general, sensitivity, PPV and accuracy were unsatisfactory (<70%), while the specificity and NPV were satisfactory (> 70%), and the agreement ranged from poor to reasonable (between 0 and 0.39). Although greater accuracy was achieved in the differentiation of healthy dogs from those with acquired and congenital heart diseases by thoracic radiography, when compared to the other studies, the modality was able only to identify healthy patients, and could not differentiate the individuals with different forms of heart disease or define the cardiac malformations. In addition, there was low reproducibility between observers, therefore, this technique should not be used as a sole screening method in dogs with suspected congenital heart diseases.
**Key words:** Cardiac Malformations. Cardiology. Diagnostic Imaging. Thorax X-ray.

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## Resumo

Os objetivos do estudo foram avaliar a acurácia da técnica radiográfica de tórax como exame de triagem nas cardiopatias congênitas em cães, identificar as principais contribuições e limitações dessa modalidade, e verificar a reprodutibilidade das avaliações realizadas por três observadores com diferentes graus de treinamento. Realizou-se um estudo interobservador, observacional, retrospectivo e prospectivo, o qual foram selecionados 90 cães, sendo 30 saudáveis, 30 com cardiopatias adquiridas e 30 com cardiopatias congênitas, que possuíam radiografia de tórax e diagnóstico ecocardiográfico confirmado. Os casos foram separados e randomizados por um mediador que não participou da leitura dos exames radiográficos, sendo que nenhum avaliador obteve acesso aos dados dos pacientes. Calculou-se os índices de sensibilidade, especificidade, valor preditivo positivo (VPP), valor preditivo negativo (VPN) e acurácia de cada observador em relação a identificação dos pacientes saudáveis, com cardiopatias adquiridas e congênitas, bem como para identificação de aumento da silhueta cardíaca e região de grandes vasos dos cães com cardiopatias congênitas. Por fim, foi obtido o coeficiente de Kappa entre os observadores a fim de verificar a reprodutibilidade das avaliações radiográficas realizadas. De modo geral, a sensibilidade, VPP e acurácia foram insatisfatórios (< 70%), enquanto a especificidade e VPN foram satisfatórios (> 70%), sendo que a concordância variou de ruim a razoável (entre 0 e 0,39). Apesar de ter sido alcançado acurácia maior na identificação de cães saudáveis, com cardiopatias adquiridas e congênitas pela radiografia de tórax quando comparado aos demais estudos, confirma-se que essa modalidade se mostrou capaz apenas de identificar o paciente saudável, não de diferenciar os indivíduos cardiopatas entre si ou de definir com maior detalhe as malformações cardíacas especificamente. Além disso, o exame radiográfico de tórax apresentou baixa reprodutibilidade entre os observadores, portanto, essa técnica não deve ser considerada como método único de triagem na suspeita de cães com cardiopatias congênitas.

**Palavras-chave:** Cardiologia. Diagnóstico por Imagem. Malformações Cardíacas. Radiografia de Tórax.

## Introduction

Congenital heart diseases are morphological and functional changes in the heart or large vessels that persist after birth (Beijerink; Oyama; Bonagura, 2017; MacDonald, 2006). These changes, in conjunction with environmental influences, result in significant variation in the severity of the disease, presentation of clinical signs and findings on complementary examinations (Strickland & Oyama, 2016). These defects reduce perfusion of oxygenated blood to the tissues, and thus represent an important cause of morbidity and mortality in dogs less than one year of age (Beijerink et al., 2017; Buchanan et al., 1999). Early diagnosis of these conditions is paramount for appropriate management, increasing the expectation and quality of life of affected animals (Oliveira et al., 2011). However, it has been previously reported that late diagnosis often occurs in cardiac malformations that do not lead to clinical signs, and that heart murmur is often the only sign observed (MacDonald, 2006). Ancillary examinations in addition to the clinical history and physical examination are necessary to differentiate the healthy patients from the affected animals or those with pulmonary disease (Beijerink et al., 2017; Satou; Lacro; Chung; Gauvreau; Jenkins, 2001).

Dogs with moderate to severe congenital heart diseases usually have abnormalities on thoracic radiographs; however, this modality cannot identify the etiology of an auscultated heart murmur, merely highlight some of the consequences of cardiac malformations (Côté et al., 2015). Radiographic examination is routinely used because it is a low-cost technique capable of providing important complementary information in the initial assessment and therapeutic management of patients (Côté et al., 2015; Schweigmann; Gassner; Maurer, 2006). For this reason, even in humans, it remains the most common screening test in patients with suspected

heart diseases (Tumkosit; Yingyong; Mahayosnond; Choo; Goo, 2012). This modality is useful in evaluating changes in cardiac size, large vessels and pulmonary vascularization. In conjunction with the clinical signs and findings of the physical examination, thoracic radiography helps to generate the list of differential diagnoses (MacDonald, 2006).

The literature is not uniform regarding the use of thoracic radiography as a diagnostic tool for congenital heart diseases. Older veterinary papers describe a high percentage of specific findings for certain cardiac malformations (Ackerman; Burk; Hahn; Hayesh, 1978; Fingland; Bonagura; Myerc, 1986; Lehmkuhl; Warew; Bonagura, 1994; Ringwald & Bonagura, 1988; Sisson; Luethy; Thomas, 1991). In contrast, a more recent study found thoracic radiology to have a low accuracy as a diagnostic method for congenital heart diseases in dogs (Lamb; Boswood; Volkman; Connolly, 2001). In human medicine, an accuracy ranging from 30% to 78% has been shown in the differentiation of healthy patients from those with congenital heart disease, and this range of accuracy was attributed to the variation in the severity of the diseases (Tumkosit et al., 2012). However, some authors still consider radiography to be a poor test, even when performed for the purpose of screening (Fonseca; Chang; Senac; Knight; Sklansky, 2005). The gold standard diagnostic method for the confirmation of congenital heart disease in animals is echocardiography (Côté et al., 2015).

A contemporary research project evaluating thoracic radiology in dogs diagnosed with congenital heart defects may provide relevant information on the applicability of this examination. Recent increases in image quality, with the introduction of digital devices in veterinary practice, might indicate that the accuracy of this method has changed over time. Therefore, the aim of this study was two-fold: (1) to evaluate the accuracy of computed thoracic radiology as a screening test for congenital heart disease in dogs, as well as to identify the main contributions and limitations of this modality; and

(2) to verify the reproducibility of the evaluations performed by three veterinarians (either radiologists or a cardiologist) with different levels of training.

## Materials and Methods

This was an interobserver, observational, retrospective and prospective study for the evaluation of radiographic examinations. Cases were selected retrospectively from the database and prospectively from the caseload presented to the Laboratories of Diagnostic Imaging and Comparative Cardiology of a veterinary teaching facility from January 2012 to June 2017. Ninety dogs were selected: 30 healthy dogs, 30 with a diagnosis of acquired heart diseases and 30 with congenital heart diseases. Thoracic computed radiographs were obtained in all patients, which also underwent a complete transthoracic echocardiogram to confirm the diagnosis. Clinical history and physical examination findings were recorded from all animals. In some patients more than one radiographic evaluation was performed, in these cases only the first examination was included, with a maximum interval of seven days between radiographic examination and echocardiography. Animals with concomitant pulmonary and vascular disease or congestive heart failure (CHF) signs were not excluded from this survey. Dogs without a definitive diagnosis obtained by echocardiographic examination, as well as those with less than three radiographic projections were not admitted into the study. This research was approved by the institutional Ethics Committee on the Use of Animals under protocol number 071/2016.

The cases were selected and randomized (https://www.randomizer.org/) by a mediator who did not participate in the evaluation of the radiographic examinations. The mediator ensured that all the images were of diagnostic quality and made them available to the observers on a digital platform in high resolution JPG format using a numerical reference. Three cases were referred every 10 days to the three observers, two of which had undertaken

radiology training, while the other was trained in cardiology (Table 1). None of the observers had access to the patients' data. Examinations were performed on standard monitors.

**Table 1**
**Description of the level of training and clinical discipline of the three observers who read the thoracic radiographs of the dogs selected for the study**

| Observer | Training Level |
|---|---|
| 1 | Professional with supervised practical training, masters, doctorate, postdoctoral, 22 years of professional experience in the field of diagnostic imaging and certified by the Brazilian College of Veterinary Radiology |
| 2 | Professional with supervised practical training, masters and 5 years of professional experience in the field of diagnostic imaging |
| 3 | Professional with supervised practical training, masters, doctorate and 7 years of professional experience in the field of cardiology |

After viewing the radiographic images the observers answered a standardized questionnaire regarding their interpretation. They identified the presence or absence of enlargements of the cardiac silhouette of the left atrium, left ventricle, right atrium, right ventricle, and large vessels, such as the aortic arch and pulmonary trunk. They were also questioned about the radiographic signs of left CHF and right CHF. Dilatation of pulmonary veins, pulmonary artery dilation, and alveolar pulmonary opacification, especially in the caudal lobes were signs of left CHF. The presence of pleural effusion, ascites or hepatosplenomegaly were indicative of right CHF (Bahr, 2018). From the identification of these findings, the observers classified the dogs into four groups: absence of CHF, left CHF, right CHF or left and right CHF. Finally, a probable diagnosis (healthy, acquired heart disease or congenital heart disease) was given and, for the patients with congenital heart diseases, the possible differential diagnoses were listed. At the end of the questionnaire there was a space for observers to comment on the examination reading.

The radiographic examination was performed following the recommendations described by Thrall and Robertson (2016), which include obtaining at least three radiographic projections (ventrodorsal or dorsoventral, left and right laterolateral). Echocardiography was performed with either an Esaote My Lab 30vet or a Philips Affiniti 50, equipped with multifrequency phased array transducers that were selected according to patient size. The echocardiographic images were obtained by veterinarians trained in echocardiography following the recommendations of the American College of Veterinary Internal Medicine (ACVIM) and the Academy of Veterinary Cardiology. The final diagnosis was based on information from the combination of modalities (two-dimensional, M-mode, spectral *Doppler* and color *Doppler*) (Thomas et al., 1993).

Descriptive statistical analysis was performed by calculating the percentages and obtaining the indices of sensitivity [true positives / (true positives + false negatives)], specificity [true negatives / (true negatives + false positives)], positive predictive value [true positives / (true positives + false positives)], negative predictive value [true negatives / (true negatives + false negatives)] and accuracy [(true positive + true negative) / total sample] for thoracic radiology. The indices were obtained for each observer in relation to the identification of the healthy dogs, and those with acquired or congenital heart diseases, as well as identification

of the enlargement of the cardiac silhouette in patients with cardiac malformations, considering the echocardiographic examination as the gold standard. The indices were considered satisfactory from 70%.

Finally, the Kappa coefficient was calculated to determine the agreement of diagnosis between the three observers, to verify the reproducibility of this examination. The level of significance was set at $P < 0.05$ and the values obtained were interpreted as: $<0$ no agreement; between 0 and 0.19 poor agreement; between 0.20 and 0.39 reasonable agreement; between 0.40 and 0.59 moderate agreement; between 0.60 and 0.79 substantial agreement; between 0.80 and 1.00 almost perfect agreement (Landis & Koch, 1977). Statistical analyzes were performed using the Laboratory of Epidemiology and Statistics software developed by the Faculty of Medicine of the University of São Paulo (USP) available in: <http://www.lee.dante.br/pesquisa/kappa/index.html>.

## Results

Thirty-six congenital heart diseases were identified in 30 dogs with cardiac malformations selected for this investigation. The congenital malformations included in our study were aortic stenosis or subaortic stenosis (n = 8), pulmonic stenosis (n = 8), persistent ductus arteriosus (n = 7), ventricular septal defect (n = 4), atrial septal defect (n = 4), mitral dysplasia (n = 3), tricuspid dysplasia (n = 1), tetralogy of Fallot (n = 1) and *cor triatriatum sinister* (n = 1). Of the animals diagnosed with acquired heart diseases, 23 dogs had mitral and tricuspid degeneration, six had only mitral valve disease and one had tricuspid degeneration.

Observers achieved an accuracy of 63 to 76% in the differentiation of healthy dogs and dogs with heart diseases, 55 to 73% in the identification of animals with acquired heart diseases and 66 to 82% in the identification of patients with congenital heart diseases. Observer 1 was the only one to reach satisfactory accuracy (> 70%) in the screening of healthy dogs (76%), with acquired (73%) and congenital heart disease (82%). Observer 2 obtained good accuracy only in the identification of the animals with congenital heart diseases (75%) and observer 3 only in the identification of the individuals with acquired heart diseases (70%). The accuracy in conjunction with the indices of sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) of all evaluators to identify healthy patients, and those with acquired and congenital heart diseases are shown in Table 2. Observer 1 listed the definitive diagnosis among the differentials in 46.6% of cases, observer 2 in 10% of cases and observer 3 in 33.3% of cases.

**Table 2**
**Description of the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and accuracy of the three observers in relation to the identification of healthy patients and patients with acquired and congenital heart diseases by radiographic examination of the thorax for all dogs included in the study (n = 90)**

| Observer | Indexes | Healthy *versus* General Heart Diseases (%) | Acquired *versus* Healthy and Congenital (%) | Congenital *versus* Healthy and Acquired (%) |
|---|---|---|---|---|
| 1 | Sensitivity | 80 | 53 | 63 |
| | Specificity | 75 | 83 | 91 |
| | PPV | 61 | 61 | 79 |
| | NPV | 88 | 78 | 83 |
| | Accuracy | 76 | 73 | 82 |
| 2 | Sensitivity | 53 | 56 | 33 |
| | Specificity | 70 | 55 | 96 |
| | PPV | 47 | 38 | 83 |
| | NPV | 75 | 71 | 74 |
| | Accuracy | 64 | 55 | 75 |
| 3 | Sensitivity | 50 | 56 | 43 |
| | Specificity | 70 | 76 | 78 |
| | PPV | 45 | 54 | 50 |
| | NPV | 73 | 77 | 73 |
| | Accuracy | 63 | 70 | 66 |

As shown in Table 2, specificity was satisfactory and greater than sensitivity for most of the classifications based on radiological examination, with all NPVs > 70% and most of the PPVs < 70%. In addition, the three observers were specific (> 70%) in the identification of healthy dogs and less sensitive (<70%) in the differentiation of patients with acquired and congenital heart diseases. The concordances regarding the identification of healthy animals, and those with acquired and congenital heart diseases were reasonable (between 0.2 and 0.39), and the identification of patients with cardiac malformations was the point of greatest agreement between the observers (0.35). The description of the Kappa coefficient calculated between the three observers on the classification of the individuals by radiological examination are detailed in Table 3.

**Table 3**
**Description of the Kappa coefficient calculated between the three observers for the identification of healthy patients and patients with acquired and congenital heart diseases by thoracic radiology including all dogs in the study (n = 90)**

| | Healthy | Acquired | Congenital |
|---|---|---|---|
| **Kappa Coefficient** | 0.30 | 0.24 | 0.35 |
| **P Value** | < 0.001 | < 0.001 | < 0.001 |
| **Confidence Interval (95%)** | 0.42 to 0.18 | 0.36 to 0.12 | 0.47 to 0.23 |

In dogs with congenital heart diseases the accuracy of identification of enlarged left atrium, left ventricle, right atrium, right ventricle, aortic arch and pulmonary trunk was < 70%, the specificity was satisfactory and greater than the sensitivity. The NPVs were satisfactory and greater than the PPVs for most of these evaluations. All the observers obtained a satisfactory value (> 70%) for sensitivity in the identification of enlarged left atrium and specificity in the identification of enlarged left ventricle and pulmonary trunk. However, all observers had low sensitivity (<70%) in the identification of left ventricular and pulmonary trunk enlargement, and low specificity and accuracy (<70%) in identifying right atrium enlargement. The description of these indices are shown in Table 4.

**Table 4**
**Description of the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and accuracy of the three observers in relation to the identification enlargement of left atrium, left ventricle, right atrium, right ventricle, aortic arch and pulmonary trunk on thoracic radiographs in patients with congenital heart defects (n = 30)**

| Observer | Indexes | LA (%) | LV (%) | RA (%) | RV (%) | AA (%) | PT (%) |
|---|---|---|---|---|---|---|---|
| | Sensitivity | 90 | 66 | 33 | 71 | 0* | 57 |
| | Specificity | 40 | 73 | 66 | 78 | 58 | 95 |
| **1** | PPV | 42 | 71 | 10 | 50 | 0* | 80 |
| | NPV | 88 | 68 | 90 | 90 | 94 | 88 |
| | Accuracy | 56 | 70 | 63 | 76 | 56 | 86 |
| | Sensitivity | 70 | 20 | 1** | 71 | 0* | 28 |
| | Specificity | 85 | 80 | 59 | 60 | 82 | 91 |
| **2** | PPV | 70 | 50 | 21 | 35 | 0* | 50 |
| | NPV | 85 | 50 | 1** | 87 | 96 | 80 |
| | Accuracy | 80 | 50 | 63 | 63 | 80 | 76 |
| | Sensitivity | 77 | 46 | 1** | 57 | 1** | 42 |
| | Specificity | 90 | 80 | 59 | 65 | 96 | 73 |
| **3** | PPV | 77 | 70 | 21 | 33 | 50 | 33 |
| | NPV | 90 | 60 | 1** | 83 | 1** | 80 |
| | Accuracy | 83 | 63 | 63 | 63 | 63 | 66 |

* No true positives were counted (nominator equal to zero)
** No false negatives were counted (denominator equal to denominator)
AA - aortic arch; LA - left atrium; LV – left ventricle; PT - pulmonary trunk; RA - right atrium; RV – right ventricle.

There was a reasonable agreement, (between 0.2 and 0.39) for evaluation of the left atrium, left ventricle, right atrium and right ventricle, and a poor agreement (between 0 and 0.19) for evaluation of the aortic arch and pulmonary trunk between all observers. Kappa coefficients for all observers in relation to the radiological examinations of dogs with congenital heart diseases are presented in Table 5. All the observers obtained high sensitivity in the identification of enlargement of the left atrium, and this was also the factor of greater agreement among them (0,37).

**Table 5**
**Description of the Kappa coefficient calculated between the three observers for identification of enlargement of left atrium, left ventricle, right atrium, right ventricle, aortic arch and pulmonary trunk on thoracic radiographs in patients with congenital heart defects (n = 30)**

|  | LA | LV | RA | RV | AA | PT |
|---|---|---|---|---|---|---|
| **Kappa Coefficient** | 0.37 | 0.25 | 0.27 | 0.3 | -0.067 | 0.097 |
| **P Value** | < 0.001 | 0.018 | 0.01 | 0.004 | Negative[*] | 0.356 |
| **Confidence Interval (95%)** | 0.57 to 0.16 | 0.45 to 0.04 | 0.47 to 0.06 | 0.51 to 0.09 | 0.13 to -0.27 | 0.3 to -0.1 |

[*] Negative value indicates disagreement.
AA - aortic arch; LA - left atrium; LV – left ventricle; PT - pulmonary trunk; RA - right atrium; RV – right ventricle.

No remodeling of cardiac chambers and large vessels, such as aortic arch and pulmonary trunk, was seen on echocardiography in 43.4% of the dogs with congenital heart diseases. There was wide variation in the percentage of dogs with congenital heart disease identified as having CHF at the time of diagnosis, (from 13.3 to 33.3% for left CHF, 3.4 to 16.7% for right CHF and 3.3 to 13.3% for left and right CHF), and 50 to 66.7% were considered normal.

## Discussion

Cases were selected for this study both retrospectively and prospectively. It was not the aim of the study to investigate prevalence of congenital heart diseases in dog. Nevertheless, the most commonly identified cardiac malformations were aortic stenosis (AS) or subaortic stenosis (SAS), pulmonic stenosis (PS) and patent ductus arteriosus (PDA). Radiological signs of enlargement of the cardiac chambers and large vessels are more often recognized in dogs with diseases leading to volume overload such as PDA, ventricular septal defect, and mitral and tricuspid valve dysplasia. In conditions that lead to pressure overload, such as AS or SAS and PS, changes are rarely identified on thoracic radiographs (Levitt; Fowler; Schuh, 1989; O'Grady; Holmberg; Miller; Cockshutt, 1989). Such aspect might have influenced the interpretation of the radiographic examinations in our study, since a large amount of dogs enrolled were diagnosed with conditions that cause pressure overload, which do not result in changes on thoracic radiographs (Figure 1).
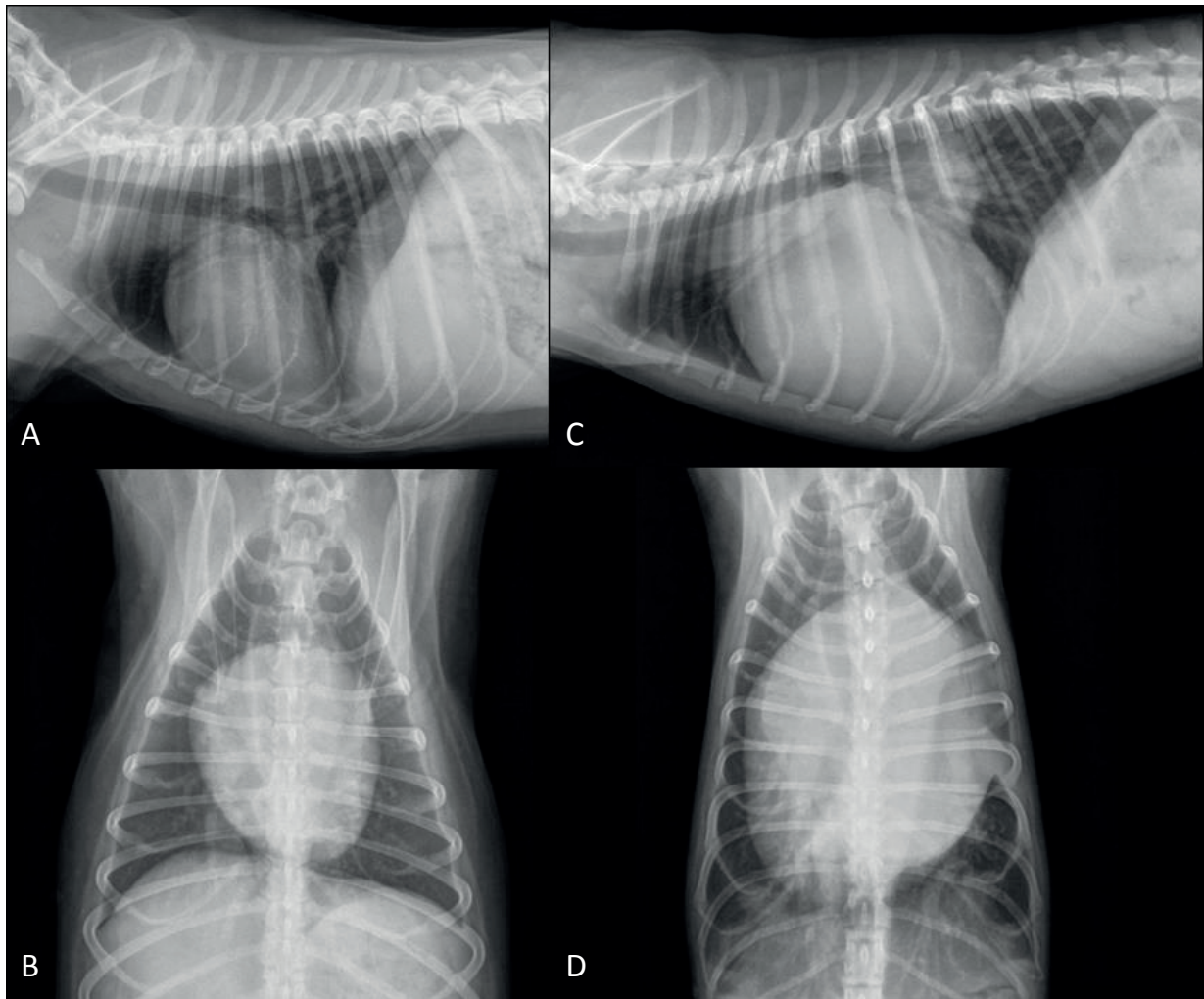
**Figure 1.** Computed radiographic images of a dog with subaortic stenosis in right lateral (A) and ventrodorsal (B) projections and of a dog with patent ductus arteriosus in right lateral (C) and ventrodorsal (D) projections. Source: Personal Archive.
Note: In images A and B there is no evidence of cardiac remodeling; whereas images C and D, show a significant increase in size of the left atrium and ventricle, dorsal displacement of the trachea, congestion of pulmonary veins, and more marked alveolar pulmonary opacification in the caudal-dorsal pulmonary lobes. These radiographs demonstrate the differences between the radiographic signs in diseases that lead to pressure overload (A and B) and diseases that lead to volume overload (C and D).

The observers in this study had a 63 to 76% accuracy in the differentiation of healthy dogs and dogs with heart diseases, 55 to 73% in the identification of animals with acquired heart diseases and 66 to 82% in the identification of patients with congenital heart diseases (Table 2). The definitive diagnosis was listed among the differentials in between 10 and 46.6% of cases of cardiac malformations, depending on the experience of the observer. Another veterinary study previously reported inferior accuracy for the screening of healthy animals and animals with heart diseases (57 and 70%) and for differentiation of patients with acquired and congenital heart diseases (49 and 61%). With respect to defining specific cardiac malformations, the same study reached intermediate accuracy (37 and 40%) compared to ours (Lamb et al., 2001). Perhaps the difference in accuracy found

between studies is attributed to the improved image quality resulting from the use of computerized radiology in the present research.

Accuracy was lower once attempts were made to identify specific cardiac malformations by radiological examination alone. In addition, all the observers were specific (> 70%) in the identification of healthy dogs and less sensitive (<70%) in the differentiation of patients with acquired and congenital heart diseases (Table 2). The radiological examination was thus able to identify the healthy individual, but not to differentiate the cause of heart disease or to identify specific cardiac malformations. One possible explanation for this finding is that some acquired and congenital heart diseases result in similar cardiac remodeling, making it difficult to identify the specific underlying disease. Thoracic radiology is an important diagnostic tool, but the more specific the diagnosis made the lower the probability of reaching a correct result using this modality (Lamb et al., 2001).

Of the dogs with cardiac malformations included in this study, 50 to 66.7% had no signs of CHF and 43.4% had no cardiac enlargement on the echocardiographic examination. In a human medical study that used thoracic radiology as a screening test to identify congenital heart diseases in asymptomatic children with heart murmurs, the accuracy was 30% in the classification of normal individuals and those with cardiac malformations (Birkebaek et al., 1999). Most studies published in the human medical literature consider this modality to have low diagnostic value when asymptomatic patients are included in the analyses (Birkebaek; Hansen; Oxhoj, 1995; Birkebaek et al., 1999; Fonseca et al., 2005; Newburger; Rosenthal; Williams; Fellows; Miettinen, 1983; Satou et al., 2001; Temmerman; Mooyaart; Taverne, 1991). Although our accuracy was higher than that obtained by Birkebaek et al. (1999), a significant percentage of the dogs had no signs of CHF or cardiac enlargement on echocardiographic examination, which may have directly influenced the results. Our accuracy would

likely be greater if only symptomatic dogs or dogs with cardiac remodeling had been enrolled.

One of the features of this study was that the specificities were satisfactory and greater than sensitivity for most of the classifications made (Table 2). High specificity with low sensitivity occurs when the examination is likely to provide more false negative results (Nunes et al., 2015). From these data, we know that some individuals with heart diseases were not identified by radiographic examination. As previously described, mild diseases or conditions that lead to pressure overload may not result in overtly visible changes on thoracic radiographs (Lamb et al., 2001; MacDonald, 2006). For this reason, it is recommended that thoracic radiology be used with caution in the identification of dogs with suspected congenital heart diseases, particularly in asymptomatic patients.

The findings of specificity and sensitivity are also supported by the predictive values. All calculated NPVs were > 70% and most PPVs were < 70% for the identification of healthy dogs and dogs with acquired and congenital heart diseases (Table 2). The NPV refers to the probability of a patient not having the abnormality when the test result is negative, while the PPV indicates the likelihood of a patient having the disease when the test result is positive (Nunes et al., 2015). So, in this study the chance of a negative result being correct was higher than the chance of a positive result being correct. As previously mentioned, this finding is supportive of thoracic radiology being more effective in the identification of healthy dogs (unchanged) as compared to dogs with heart diseases.

Observer 1 was the only veterinarian to reach satisfactory accuracy (> 70%) in the screening of dogs by radiological examination. Observer 2 obtained good accuracy only in the identification of animals with congenital heart diseases and observer 3 only in the identification of individuals with acquired heart diseases (Table 2). In addition, the concordances between the observers for the classification of patients between the groups were

only reasonable (Table 3). The discrepancy between the accuracy values obtained and the reasonable agreement is explained by the difference in level and time in years of training of each observer, since the observer with the highest degree of training and greater time of professional practice was the one who reached the highest accuracy rates in the use of radiology as a screening test (Table 1).

While the accuracy of identification of enlargements of specific regions of the cardiac silhouette in dogs with congenital heart diseases was < 70%, the specificity was satisfactory and greater than the sensitivity. In addition, the NPV was satisfactory and greater than the PPV for most of these evaluations (Table 4). Satisfactory sensitivity (> 70%) for all observers was only reached for the identification of left atrial enlargement. This was possibly attributable to one third of the patients enrolled having patent ductus arteriosus (PDA) and mitral dysplasia (MD), conditions that are known to cause volume overload and substantial increases in the size of left atrium (Lamb et al., 2001). Radiological examination failed to identify any other specific changes in the cardiac silhouette. Other veterinary researchers have previously reported this finding (Lombard & Ackerman, 1984; Lombard & Spencer, 1985), probably because the size and shape of cardiac silhouette in dogs are influenced by body condition score and the thoracic shape in some breeds. Therefore, radiology becomes imprecise in identifying cardiac and large vessels enlargement in these animals (Thrall & Robertson, 2016).

Evaluation of the left atrium showed a high sensitivity for all observers and was also the factor of greatest agreement between them. Nonetheless, only a reasonable agreement (between 0.2 and 0.39) was documented (Table 5). This was probably ascribed to the different degree of training of the observers who participated in this study. The worst concordances (between 0 and 0.19) were seen for the identification of enlarged aortic arch and pulmonary trunk (Table 5). This may have been due to the small number of patients with enlarged aortic

arch and pulmonary trunk (low number of true positives or false negatives), directly influencing Kappa coefficient calculations.

There are a number of limitations in this study, which should be acknowledged. Patient information was concealed from the observers. This may have caused a bias in the interpretation because in the regular clinical scenario data such as age, body score, breed and clinical history is known to the radiologist. The reproducibility data of this work should be interpreted with caution, since only three observers participated in the study and their methods of reading and experience of each one were not evaluated.

## Conclusion

Although we achieved a higher accuracy in the identification of healthy dogs, and those with acquired and congenital heart disease by thoracic radiology than previous studies, radiographic examination was only able to identify healthy patients, and could not differentiate between the individuals with different forms of heart disease nor define the specific cardiac malformations. In addition, radiological examination showed low reproducibility between the observers, therefore, this modality is not recommended as a sole screening tool for dogs with suspected congenital heart diseases.

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