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Reference values for vertebral heart size and manubrium heart score for healthy Border Collies

Valores de referência para vertebral heart size e manubrium heart score para Border Collies saudáveis

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Abstract
This study aimed to establish reference values for vertebral heart size (VHS) and manubrium heart score (MHS) in healthy adult Border Collies. The study utilized 12 dogs, both male and female, aged between one and nine years. All dogs exhibited normal results on B- and M-mode echocardiography. Thoracic radiographs were taken in left lateral (LL), right lateral (RL), and ventrodorsal (VD) recumbency. Both subjective and objective analyses were conducted by two evaluators. The reproducibility of the objective radiographic measurements was excellent (P<0.001), with the following mean values and standard deviations: VHS LL = 9.95 ± 0.47; VHS RL = 10.10 ± 0.51; VHS VD = 10.84 ± 0.61; Short-MHS RL = 2.10 ± 0.17; Long-MHS RL = 2.57 ± 0.19; Overall MHS RL = 4.65 ± 0.33; Short-MHS VD = 2.13 ± 0.22; Long-MHS VD = 2.94 ± 0.26, and Overall MHS VD = 5.03 ± 0.42. This study contributes to the standardization of VHS and MHS measurements, thereby aiding in the evaluation of the cardiac silhouette of Border Collies.

Resumo
Objetivou-se estabelecer valores de referência para *vertebral heart size* (VHS) e *manubrium heart size* (MHS) para cães saudáveis da raça Border Collie. Foram utilizados doze cães, machos e fêmeas, com idade entre um e nove anos. Todos os animais apresentaram exame ecocardiográfico normal em modo B e modo M. Foram realizadas radiografias torácicas nas projeções laterolateral direita (LLD), laterolateral esquerda (LLE) e ventrodorsal (VD). Análises subjetivas e objetivas foram realizadas por dois avaliadores. A reprodutibilidade das mensurações radiográficas objetivas foi excelente (P<0.001). Os valores médios e desvio padrão encontrados foram: VHS LLE = 9.95 ± 0.47; VHS LLD = 10.10 ± 0.51; VHS VD = 10.84 ± 0.61; MHS-curto LLD = 2.10 ± 0.17; MHS-longo LLD = 2.57 ± 0.19; MHS LLD geral = 4.65 ± 0.33; MHS-curto VD = 2.13 ± 0.22; MHS-longo VD = 2.94 ± 0.26, e MHS VD geral = 5.03 ± 0.42. O presente estudo contribuiu para a padronização das mensurações VHS e MHS, auxiliando na avaliação radiográfica da silhueta cardíaca de Border Collies.
Palavras-chave: cão; coração; radiografia torácica; vértebra.

1 | Introduction

The cardiac silhouette's radiographic evaluation is typically conducted using a subjective protocol. This protocol considers the heart's position in relation to the intercostal spaces in lateral views as well as the space the cardiac silhouette occupies relative to the thorax size in ventrodorsal or dorsoventral views (Owens and Biery, 1999).

The literature outlines various methods for the objective evaluation of the cardiac silhouette (Fernandez et al., 2023) to achieve more precise measurements. The vertebral heart size (VHS) (Buchanan and Bücheler, 1995) entails measuring the short- and long-axis of the cardiac silhouette in lateral views. These measurements are then summed and compared to the corresponding number of vertebral bodies, beginning from the cranial endplate of the fourth thoracic vertebra (Bodh et al., 2016). Consequently, VHS is a figure that correlates the size of the heart with the size of the animal (Castro et al., 2011). Buchanan and Bücheler (1995) suggested a mean VHS of 9.7 ± 0.5 vertebrae as the upper limit for the heart size of healthy dogs across various breeds. Subsequently, Buchanan (2000) proposed a VHS of 10.5 as the normal for most canine breeds.

Significant breed variation exists, encompassing thoracic conformation and the size of the cardiac axis (Buchanan, 2000; Bodh et al., 2016; Fernandez et al., 2023). The VHS reference values specified for particular dog breeds, such as the Whippet (Bavegems et al., 2005), Australian Cattle Dog (Luciani et al., 2019), and Cavalier King Charles Spaniel (Bagardi et al., 2021), exceed the general values previously suggested (Buchanan and Bücheler, 1995).

The VHS method is commonly employed for diagnosing cardiomegaly (Mostafa and Berry, 2017). However, its effectiveness is limited in cases where vertebral malformations related to breed (such as hemivertebrae, transitional, or butterfly vertebrae) are present (Fernandez et al., 2023) or in instances of degenerative processes like spondylosis deformans or intervertebral disc space narrowing. These alterations can potentially result in cardiopathy misdiagnoses due to inaccurate measurements (Lamb et al., 2001; Bagardi et al., 2022). Furthermore, VHS measurements in healthy dogs and cats may be affected by respiratory and cardiac cycles, which can alter the radiographic appearance of the cardiac silhouette (Mostafa and Berry, 2017).

The manubrium heart score (MHS) correlates the manubrium of the sternum with the cardiac silhouette (Mostafa and Berry, 2017). The manubrium, characterized as a prominent, elongated structure, is readily identifiable in lateral radiographs (Fernandez et al., 2023).

The MHS method, akin to the VHS, employs measurements of the cardiac silhouette's short- and long-axis, juxtaposing them with the length of the manubrium of the sternum (Mostafa and Berry, 2017). This process yields the short axis to manubrium length ratio (short-MHS), the long axis to manubrium length ratio (long-MHS), and the combined short- and long-axis to manubrium length ratio (overall MHS) (Mostafa and Berry, 2017).

While the literature provides VHS reference values for various dog breeds, to our knowledge, this is the first study involving Border Collies. Compared to the general canine population, this dog breed presents specific cardiac morphological particularities on echocardiography such as larger left ventricular internal dimension in diastole and lower fractional shortening (Jacobson et al., 2013). For that reason, we supposed that this unique breed should not be evaluated using the general VHS values previously published. Therefore, our objective was to establish reference values for both VHS and MHS for Border Collies, thereby contributing to the cardiac evaluation of this breed.

2 | Materials and Method

The research was conducted at the Radiology Service of the Veterinary Hospital, part of the Faculty of Animal Sciences and Food Engineering at the University of São Paulo (FZEA-USP). The study included client-owned, healthy Border Collies aged between one and nine years. The selection process did not consider the sex or body weight of the dogs. Echocardiography served as the screening test, and any animals exhibiting alterations on B- or M-mode echocardiography or thoracic radiographs were excluded from the study.

2.1 | Radiography

Radiographs were procured using an Altus ST stationary X-ray machine (630 mA and 125 kV, SAWAE®). The radiographic technique employed was contingent on the correlation between kV and mAs, which varied according to the thickness of the thorax. There was used a fixed mA of 200 for the thoracic studies. Average thickness of the thorax was 28.6cm (ranging from 25 to 32.5cm) for the lateral views, and 32.8cm (ranging from 28.5 to 37.5cm) for the ventrodorsal views. Radiographs were laid flat on a negatoscope for manual measurements using a ruler. These measurements were conducted by a fourth-year veterinary student and a professor specializing in diagnostic imaging. Thoracic radiographs were taken in the right lateral (RL), left lateral (LL), and ventrodorsal (VD) recumbences. The dogs were manually restrained without the use of sedation or anesthesia. The forelimbs were extended cranially to ensure perfect alignment of costochondral junctions on lateral projections and thoracic vertebral bodies superimposed on the sternum in ventrodorsal projections. The subjective evaluation involved analyzing the cardiac silhouette on the ventrodorsal projection and comparing the cardiac thickness to the thoracic width. The broadest part of the cardiac silhouette should not exceed two-thirds of the thoracic width (at the level of the eighth thoracic vertebra, T8) (Bodh et al., 2016). In the lateral projection, the size of the cardiac silhouette was compared to the intercostal spaces. A normal canine heart should occupy between 2.5 and 3.5 intercostal spaces (Kealy and McAllister, 2005). Additionally, the position of the thoracic trachea, if dorsally displaced and parallel to the spine, may indicate cardiomegaly (Kealy and McAllister, 2005). An objective evaluation of the cardiac silhouette incorporated the VHS and MHS measurements. Each evaluator performed measurements in triplicate.

2.2 | VHS measurements

VHS measurements were performed according to Buchanan and Bücheler (1995). The study was performed using RL, LL, and VD projections.

1)The long axis (L) extends from the most ventral aspect of the tracheal carina to the cardiac apex, as seen in lateral views (Figure 1). Alternatively, in ventrodorsal views, it corresponds to the distance between the apex and base of the heart (Figure 2).

2)The short axis (S) is perpendicular to the long axis at the point of greatest thickness.

3)The measurement of the (L) and (S) lines in centimeters and their transposition to the vertebral spine, commencing at the cranial endplate of the fourth thoracic vertebra (T4), as viewed laterally, is depicted in Figure 2.

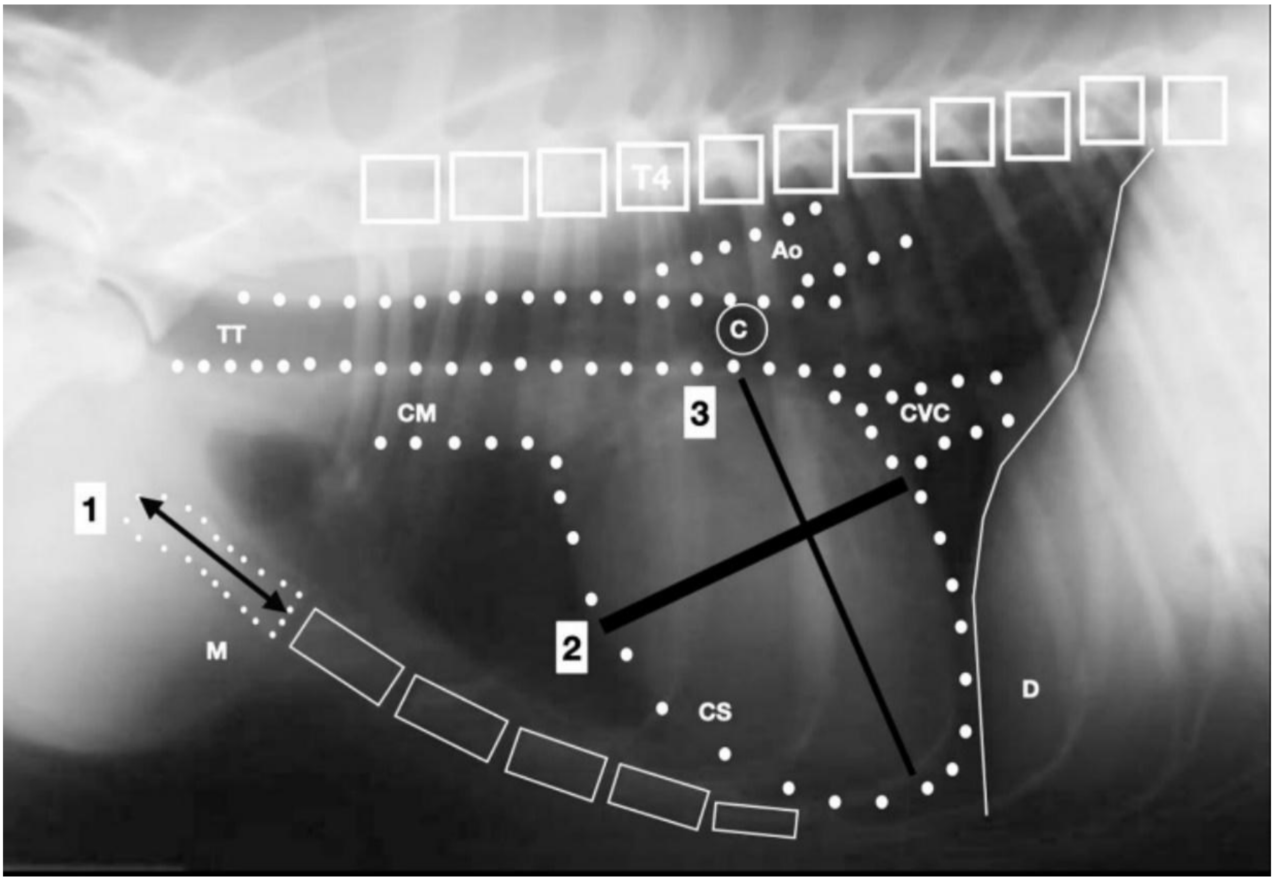

Figure 1. A thoracic radiograph in lateral view presenting the objective measurements used to estimate the cardiac size with vertebral heart size and manubrium heart score methods. Measures include the manubrium length (1) and the short (2) and long (3) axes of the cardiac silhouette. Ao: aorta; C: tracheal carina; CM: cranial mediastinum; CS: cardiac silhouette; CVC: caudal

vena cava; D: diaphragm; M: manubrium; T4: fourth thoracic vertebrae; and TT: thoracic trachea. Adapted from Buchanan and Bücheler (1995).

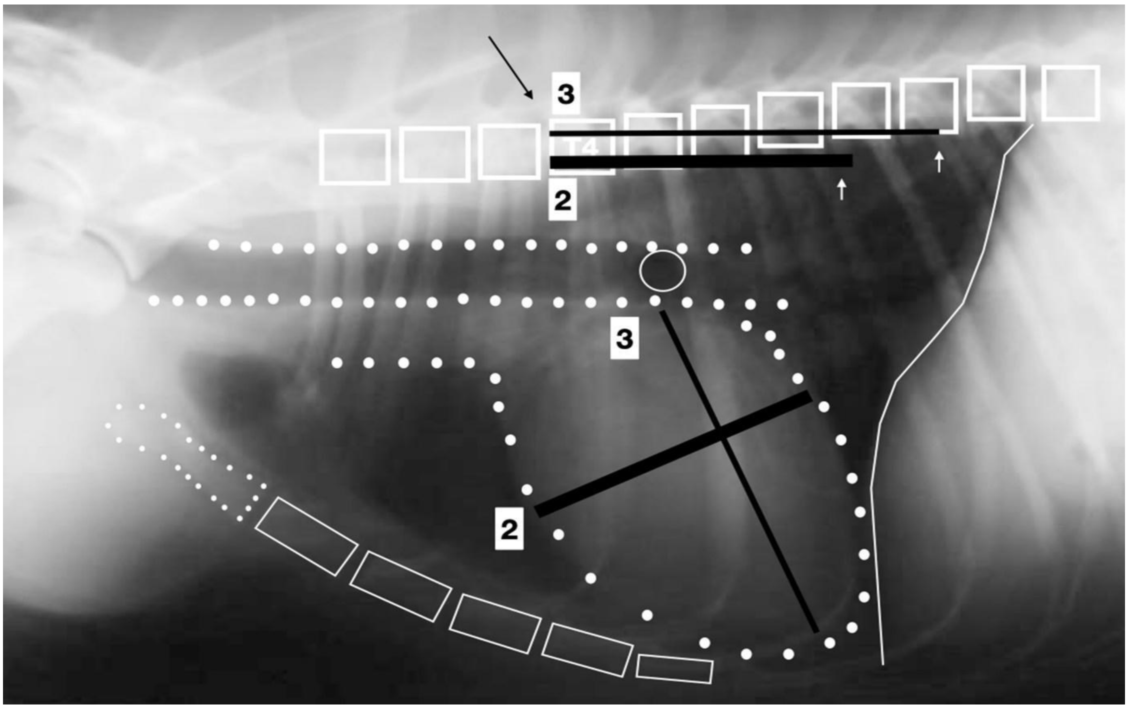

Figure 2. A thoracic radiograph in lateral view presenting the transposition of measurements to the vertebral spine. Measurements of the short- (2) and long-axis (3) of the cardiac silhouette were transposed to the vertebral spine, beginning at the cranial endplate of T4 (black arrow). At each endpoint (white arrows), a number was given associated with the corresponding number of vertebrae (i.e., short axis = 4.2 vertebrae, and long axis = 5.7 vertebrae). VHS is given by the summation of short- and long-axis measurements (i.e., 4.2 + 5.7 = 9.9 vertebrae). T4: fourth thoracic vertebrae. Adapted from Buchanan and Bücheler (1995).

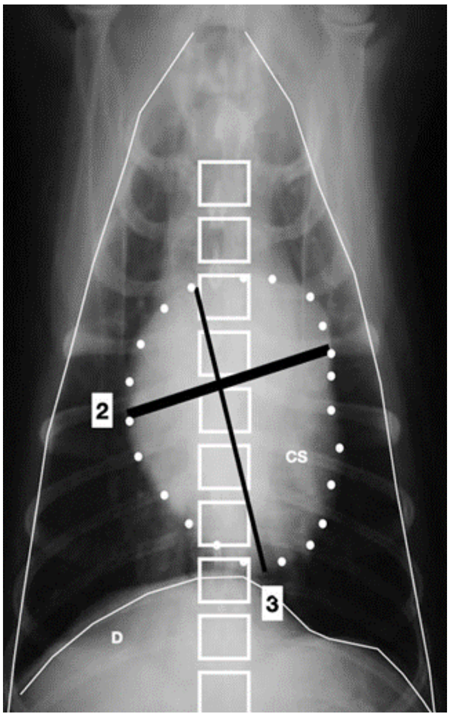

Figure 3. A thoracic radiograph in ventrodorsal view presenting the measurements used to estimate the vertebral heart size and manubrium heart size. Measures include the short- (2) and long axis (3) of the cardiac silhouette. CS: cardiac silhouette; D: diaphragm. Adapted from Buchanan and Bücheler (1995).

After the transposition of the measurements, the distance, equivalent to the length of the transposed lines, should be expressed in terms of the number of vertebrae, with measurements as precise as decimals. For instance, in Figure 2, the long axis equals 5.7 vertebrae, and the short axis equals 4.2 vertebrae. The VHS is the sum of the long- and short-axis measurements, expressed in vertebrae. For instance, in Figure 2, the VHS is 9.9 vertebrae.

2.3 | MHS measurements

Measurements of MHS were taken in both RL (Figure 1) and VD projections (Figure 3), measured in centimeters. This was done in accordance with the methodology outlined by Mostafa and Berry (2017).

1) The long axis (L) extends from the most ventral aspect of the tracheal carina to the cardiac apex when viewed from the right lateral (RL) perspective. Alternatively, in a ventrodorsal view, it

corresponds to the distance between the apex and base of the heart.

2) The short axis (S) is defined as being perpendicular to the long axis at the point of greatest thickness.

The measurements for the short- and long-axis, in both RL and VD views, were correlated with the length of the manubrium, which was measured in the RL view, as follows:

1) Short-MHS = short axis:manubrium length;

2) Long-MHS = long axis:manubrium length;

3) Overall MHS = short- + long axis:manubrium length.

2.4 | Statistics

Quantitative data are presented as the mean ± standard error. We performed an analysis of variance, establishing minimum and maximum values, the mean, median, and standard deviation for each parameter. This was done using a pool of six measurements, with three measurements per evaluator. The reproducibility of the measurements was assessed using the intra-class correlation coefficient for VHS and MHS measurements between two evaluators: a radiologist and a trainee. This assessment considered mean values and yielded a p-value of less than 0.001.

3 | Results

The study involved 12 healthy Border Collies, averaging 37.16 ± 27.03 months in age (ranging from 12 to 108 months) and 21.34 ± 4.25 kg in body weight (ranging from 15.3 to 25.8 kg). The sample comprised eight males (66.6%) and four females (33.3%), with no distinction made between sex and reproductive status (intact and neutered animals).

The analysis was conducted based on a pool of measurements, with three per evaluator. The reproducibility, as indicated by the intra-class correlation coefficient, was excellent for each measurement, in line with the interpretation previously published by Koo and Li (2016). Higher the intra-class correlation coefficient, better the agreement between observers, so that an excellent reproducibility means that there were no significant differences between measurements among observers. This facilitated the establishment of reference values, including minimum, maximum, mean, median, and standard deviation values, specifically for Border Collies (Table 1, Figures 4 and 5).

The values established for VHS were 9.95 ± 0.47 (LL), 10.10 ± 0.51 (RL), and 10.84 ± 0.61(VD). Manubrium heart score values obtained with the right lateral recumbency (RL) were 2.10 ± 0.17 (Short-MHS RL), 2.57 ± 0.19 (Long-MHS RL), and 4.65 ± 0.33 (Overall MHS RL). Manubrium heart score values obtained with the ventrodorsal recumbency (VD) were 2.13 ± 0.22 (Short-MHS VD), 2.94 ± 0.26 (LonMHS VD), and 5.03 ± 0.42 (Overall MHS VD)

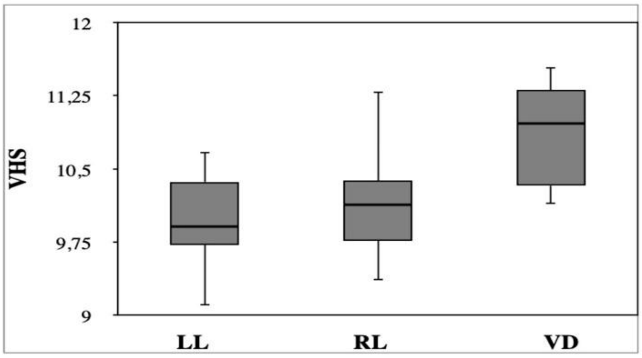

Figure 4. Box-and-Whisker plot of the measurements of the vertebral heart size (VHS) for normal Border Collie dogs demonstrating the minimum value, 25th percentile value, median, 75th percentile, and maximum value. LL: left lateral radiograph; RL: right lateral radiograph; VD: ventrodorsal radiograph.

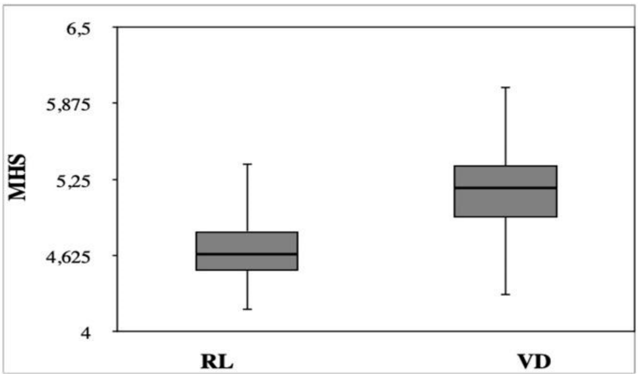

Figure 5. Box-and-Whisker plot of the measurements of the overall Manubrium Heart Score (MHS) for normal Border Collie dogs demonstrating the minimum value, 25th percentile value, median, 75th percentile, and maximum value. RL: right lateral radiograph; VD: ventrodorsal radiograph.

4 | Discussion

The objective assessment of the cardiac silhouette enhances accuracy and reduces discrepancies compared to subjective analysis, thereby positively influencing the radiographic diagnosis of cardiopathies between evaluators with varying expertise levels. Certain studies have indicated that variations in VHS values among evaluators are more likely due to inconsistencies in identifying anatomical reference points than the individual expertise of each observer (Luciani et al, 2019; Bagardi et al., 2021).

Table 1. Standard values and intra-class correlation coefficient for radiographic measurements of the cardiac silhouette in Border Collies

Measurement	Minimum	Maximum	Mean	Median	SD	Intra-class Correlation Coefficient (P-value < 0.001)
VHS LL (v)	8.95	10.90	9.95	9.90	0.47	0.9653
VHS RL (v)	8.90	11.40	10.10	10.10	0.51	0.8766
VHS VD (v)	9.59	12.40	10.84	10.80	0.61	0.9436
Manubrium (cm)	3.10	5.60	4.60	4.60	0.51	0.8778
Short axis (RL) (cm)	8.10	10.90	9.61	9.55	0.84	0.9784
Long axis (RL) (cm)	9.40	13.50	11.78	11.85	1.10	0.9703
Short-MHS = short axis:manubrium (RL)	1.80	2.61	2.10	2.03	0.17	0.9998
Long-MHS = long axis:manubrium (RL)	2.19	3.06	2.57	2.53	0.19	0.9476
Overall MHS = short- + long axis:manubrium (RL)	4.09	5.48	4.65	4.60	0.33	0.9728
Short axis (VD) (cm)	7.50	12.00	9.77	9.75	0.94	0.9139
Long axis (VD) (cm)	10.30	16.40	13.45	13.20	1.37	0.9203
Short-MHS = short axis:manubrium (VD)	1.68	2.70	2.13	2.15	0.22	0.9748
Long-MHS = long axis:manubrium (VD)	2.39	4.03	2.94	2.91	0.26	0.9999
Overall MHS = short axis + long axis:manubrium (VD)	3.86	6.04	5.03	5.05	0.42	0.9622

VHS: vertebral heart size; LL: left lateral view; RL: right lateral view; v: vertebrae; cm: centimeter; MHS: manubrium heart size; VD: ventrodorsal view; SD: standard deviation.

Our research involving Border Collies revealed elevated VHS values in comparison to the generic reference proposed for all dog breeds (Buchanan and Bücheler, 1995). This discovery aligns with prior studies conducted on Whippets (Bavegems et al., 2005), the Australian Cattle Dog (Luciani et al., 2019), Cavalier King Charles Spaniel dogs (Bagardi et al., 2021), and also German Shepherd dogs (Nabi et al., 2014). Interestingly, a study with Belgian Malinois dogs (Almeida et al., 2015), showed lower values of VHS when compared to the generic reference values.

Our research did not aim to investigate the impacts of body weight on VHS and MHS measurements. Prior studies have indicated no correlation between body weight and VHS measurements (Greco et al., 2008; Bodh et al., 2016). This contradicts a study on Norwich Terriers, which noted variations in VHS values based on body weight and body condition score (Taylor et al., 2020). Regarding MHS measurements, a connection between body weight and manubrium length has been reported (Mostafa and Berry, 2017).

Previous studies have found no variation in VHS with age (Lamb et al., 2001; Greco et al., 2008; Bodh et al., 2016; Mostafa et al., 2020). The current research did not aim to explore the impact of age on the measurement of VHS and MHS. Nevertheless, we standardized the assessment for dogs older than 12 months, adhering to the protocols described earlier (Lamb et al., 2001; Bavegems et al., 2005; Bodh et al., 2016).

Our study did not focus on the effect of sex, given that several authors have reported no significant difference in VHS values between males and females (Buchanan and Bücheler, 1995; Bavegems et al., 2005; Greco et al., 2008; Nabi et al., 2014; Almeida et al., 2015; Luciani et al., 2019; Bagardi et al., 2021); This consideration also takes into account the minimal variation in body weight between male and female dogs of certain breeds (Luciani et al., 2019). However, it is worth noting that some authors have observed lower VHS values in female dogs compared to males (Lamb et al., 2001).

Luciani et al. (2019) and other authors have suggested a potential physiological enlargement of the cardiac silhouette in active dogs, including working or athletic dogs. Bavegems et al. (2005) further reported that trained dogs might exhibit an enlarged left ventricle, resulting in higher VHS values. Our study sample comprised dogs with varying activity levels. However, none of the subjects under study had specific training in sports such as agility or other modalities. Consequently, we did not investigate the impact of activity level on VHS and MHS values.

Our study revealed elevated VHS values for RL projections in comparison to left lateral (LL) views. This result aligns with the findings of some researchers (Bavegems et al., 2005; Greco et al., 2008; Bodh et al., 2016; Luciani et al., 2019), while contradicting others (Buchanan and Bücheler, 1995; Buchanan, 2000; Nabi et al., 2014; Bagardi et al., 2021). For the MHS assessment, we conducted measurements in the RL view to mitigate potential influences from the rounded cardiac silhouette observed in LL projections, as previously outlined (Mostafa and Berry, 2017).

Differences in VHS values, as observed in ventrodorsal and dorsoventral views, have been documented in Whippet dogs. Ventrodorsal projections were found to yield higher VHS values (Bavegems et al., 2005). This phenomenon may be attributed to potential magnification in ventrodorsal views (Mostafa and Berry, 2017). However, the present study did not explore the impact of ventrodorsal versus dorsoventral projections.

While some researchers have noted that delineating the manubrium of the sternum can occasionally pose a challenge (Mostafa and Berry, 2017), the current study found no such difficulties. The identification and measurement of the manubrium length were straightforward in all the radiographs evaluated.

The correlation among evaluators for radiographic evaluations of cardiac silhouettes was excellent. This underscores the high reproducibility of thoracic cavity radiographic evaluations in dogs, as demonstrated by VHS measurements (Fernandez et al., 2023). Both the VHS (Buchanan and Bücheler, 1995) and MHS (Mostafa and Berry, 2017) methods proved to be highly effective for screening evaluations of the cardiac silhouette, exhibiting excellent reproducibility between the trainee and the expert evaluator.

The cardiac silhouette in dogs with cardiac failure tends to be rounded, in contrast to the silhouette observed in healthy dogs. Consequently, dogs with cardiopathies typically exhibit higher VHS values compared to their healthy counterparts (Lamb et al., 2000; Mostafa et al., 2020). An increase in short-MHS in LL views, despite a seemingly normal long-MHS, may suggest cardiomegaly characterized by enlarged left or right cardiac chambers. Conversely, an increase in long-MHS in the RL view, despite a normal short-MHS, may indicate enlargement of the left atrium, ventricle, or both. In such instances, the cardiac silhouette tends to assume an elongated shape (Mostafa and Berry, 2017). Our forthcoming research will involve a comparative analysis of radiographs from both healthy and symptomatic Border Collies

5 | Conclusion

The current study presents mean values and standard deviations for normal VHS and MHS in healthy adult Border Collies. The values are as follows: VHS LL = 9.95 ± 0.47; VHS RL = 10.10 ± 0.51; VHS VD = 10.84 ± 0.61; Short-MHS RL = 2.10 ± 0.17; Long-MHS RL = 2.57 ± 0.19; Overall MHS RL = 4.65 ± 0.33; Short-MHS VD = 2.13 ± 0.22; Long-MHS VD = 2.94 ± 0.26, and Overall MHS VD = 5.03 ± 0.42. These measurements can serve as a reference for diagnosing cardiac diseases in Border Collies and other breeds.

6 | Conflict of Interest Statement

Authors declare no conflicts of interest, financial or otherwise.

7 | Ethics Committee

This study was previously approved by the local Ethical Committee for Animal Use (CEUA-FZEA-USP) under protocol number 3826270817.

8 | Acknowledgements

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