Acta Scientiae Veterinariae, 2024. 52: 1940.

RESEARCH ARTICLE
Pub. 1940

ISSN 1679-9216

# Echocardiography in Healthy Dogs - Comparison of Apical 5C and Subxiphoid Windows

**Daniele Clímaco Marques[1], Renan Paraguassu de Sá Rodrigues[2], Paulo Vitor Silva de Carvalho[1], Andrezza Braga Soares da Silva[1], Kelvin Ramon da Silva Leitão[1], Francisco das Chagas Araújo Sousa[3], Maria Angelica Parentes da Silva Barbosa[1], Jacyara de Jesus Rosa Pereira Alves[4], Amilton Paulo Raposo Costa[5] & Flávio Ribeiro Alves[5]**

**ABSTRACT**

***Background*:** Echocardiography is one of the most used diagnostic methods in Veterinary Cardiology for the investigation of heart diseases. This stands out for being a non-invasive technique, readily available and that generates satisfactory results in hemodynamic monitoring compared to other invasive techniques. However, some parameters are still not well established in Veterinary Medicine. This work aims to perform a comparative echocardiographic study of the hemodynamic profile of the outflow tract of the left ventricle (LVOT) between the apical 5-chamber and subxiphoid windows in healthy dogs, in order to characterize the difference between their hemodynamic indices.

***Materials, Methods & Results*:** An observational, prospective study was carried out in which 30 clinically healthy dogs of both sexes of small to medium-sized breeds were examined. All animals underwent a complete screening echocardiographics examinations without sedation. After the complete examination, the left ventricular outflow tract (LVLVD) internal diameter was measured in the parasternal window on the long axis at the level of the aortic valve annulus during systole. The LVOT cross-sectional area was calculated using the formula $\pi r^2$. The LVOT velocity-time integral (VTI) was measured by pulsed Doppler, with the cursor positioned before the aortic valve in the apical 5-chamber and subxiphoid window. Stroke volume (SV) was the result of the product of LVOT IVT measurements and LVOT cross-sectional area. Cardiac output (CO) was estimated by the product of SV and heart rate (HR). VTI, SV and DC were comparable between the 2 groups and showed a statistically significant difference ($P < 0.05$). The values for the subxiphoid window were higher compared to the values found in the apical 5-chamber window.

***Discussion*:** CO and SV can be underestimated when VTI is measured with the probe in an apical position. With the results of the present research, it is speculated that the measurement of the LVOT flow in a subxiphoid position is the method of choice for the acquisition of more accurate data on CO and SV. This difference in precision is justified by the dependence of the Doppler beam on alignment with blood flow. A Doppler signal with an intercept angle closer to 0° is preferable to obtain reliable values. The subxiphoid transducer provides more consistent alignment of the ultrasound beam with the aortic blood flow. Previous studies in humans have reported that vessel diameter has a greater relevance in the variation of cardiac output. In the present study, the variables that presented the highest correlation value were the LVSD and CO, in both acquisition methods. Studies performed in humans have suggested that cardiac output and VTI do not correlate with body index or weight, concluding that vessel diameter has a greater relevance in the variation of cardiac output. In line with previous human studies, the LVOT VTI allows for early identification of cardiogenic shock. In dogs, it has been used as a substitute for SV. This approach eliminates errors in the determination of the LVOT cross-sectional area defined by the formula $\pi r^2$. In addition, the VTI has also been used in therapeutic guidance regarding fluid responsiveness. In these circumstances, the level of sensitivity and precision of the LVOT flow measurement becomes worrying, since the present research demonstrates a variability of hemodynamic profiles between 2 acquisition techniques in healthy dogs. Future studies are needed to investigate its application in Veterinary Medicine, in addition, studies involving reference data are needed.

**Keywords:** canines, Doppler, diagnostic imaging, cardiology, cardiovascular diseases, hemodynamics, LVLVD, LVOT.

DOI: 10.22456/1679-9216.134503

Received: 28 October 2023 Accepted: 8 March 2024 Published: 3 April 2024

[1]Postgraduate Program in Technologies Applied to Animals of Regional Interest (PPGTAIR); [4]Coloproctology and Colorectal Surgery Service of the University Hospital & [5]Department of Veterinary Morphophysiology (DMV), Center for Agrarian Sciences (CCA), Federal University of Piauí (UFPI), Teresina, PI, Brazil. [2]School of Veterinary Medicine, Federal University of Cariri (UFCA), Crato, CE, Brazil. [3]Department of Medicine, State university of Piauí (UESPI), Teresina. CORRESPONDENCE: F.R. Alves [flavioribeiro@ufpi.edu.br]. Department of Veterinary Morphophysiology, CCA - UFPI. Rua Dirce de Oliveira n. 3397. Bairro Ininga. CEP 64049-550 Teresina, PI, Brazil.

## INTRODUCTION

The transthoracic echocardiography is one of the diagnostic methods most commonly used in Veterinary Cardiology for the investigation of cardiovascular diseases [9]. This is due to the fact that this modality provides a quick, accurate, non-invasive and reproducible diagnosis [12]. The advances in recent years applied to this method are notable, related to the introduction, validation and improvement of diagnostic techniques [24]. This makes possible the early identification of hemodynamic and morphofunctional changes in the heart [3].

Hemodynamic monitoring is of fundamental importance in the management of hemodynamically unstable patients [29]. There are several modalities that allow this monitoring, however, echocardiography transthoracic surgery has become a readily available technique that generates satisfactory results compared to other invasive techniques [4]. Although this tool is useful in hemodynamic monitoring, some parameters are still not well established in Veterinary Medicine [24]. Previous studies have demonstrated the existence of variability in aortic flow velocity in different echocardiographic windows in dogs [1,23]. However, these studies superficially emphasize only the peak velocity or the velocity-time integral, without demonstrating the impact on the measurement of other hemodynamic variables.

This work aims to perform a comparative echocardiographic study of the hemodynamic profile of the LVOT flow in the apical 5-chamber and subxiphoid windows in healthy dogs, in order to characterize the difference between their hemodynamic indices.

## MATERIALS AND METHODS

### *Animals*

An observational, prospective study was carried out, in which 10 clinically healthy dogs of both sexes, of small to medium breeds, ranging from 5 to 13-year-old and weighing between 3 and 20 kg, were examined.

Inclusion criteria: animals considered healthy based on physical examination, complete blood count, serum biochemistry, echocardiogram and electrocardiogram.

Exclusion criteria: pregnant bitches, animals that had arrhythmias, congenital heart disease, systemic arterial hypertension, aortic insufficiency and other acquired heart diseases. Also, dogs showing signs of systemic changes due to parasitic or infectious diseases were excluded from the research.

### *Echocardiographic exam*

Echocardiographic examinations were performed without sedation, with animals positioned in right lateral recumbency, left recumbency and dorsal recumbency on appropriate table. Ultrasound equipment (Vivid IQ)[1] coupled to a 4.0-13 MHz multifrequency sectoral transducer with simultaneous electrocardiographic recording. All animals underwent a complete screening echocardiographic examination according to published guidelines [15,27].

Then, the left ventricular outflow tract (LVOTD) internal diameter was measured in the parasternal window on the long axis at the level of the aortic valve annulus during systole. The left ventricular outflow tract (LVOT) cross-sectional area was calculated using the formula $\pi r^2$. The LVOT velocity-time integral (VTI) was measured by pulsed Doppler before the aortic valve in the apical 5-chamber and subxiphoid window (Figure 1). Stroke volume (SV) was the result of the product of LVOT IVT measurements and LVOT cross-sectional area. Cardiac output was estimated by the product of SV and heart rate (HR) [5,30].

### *Statistical analysis*

Data were tabulated and grouped according to the echocardiographic windows used to determine the LVOT volumetric flow, respectively: 5C apical and subxiphoid windows. Subsequently, the data were analyzed in "Excel" and GraphPad "Software" Prism 8[2], being submitted to the normality test (Shapiro - Wilk test), correlation test and average test (Tukey's test), to assess whether the data are normal, if the quantitative variables studied (LVLVD, VTI, SV, HR, CO, weight and age) are modified together and if there is a statistically significant difference between the hemodynamic variables between the apical 5-chamber and subxiphoid window data. In the analysis, a *P* equal to 5% was used.

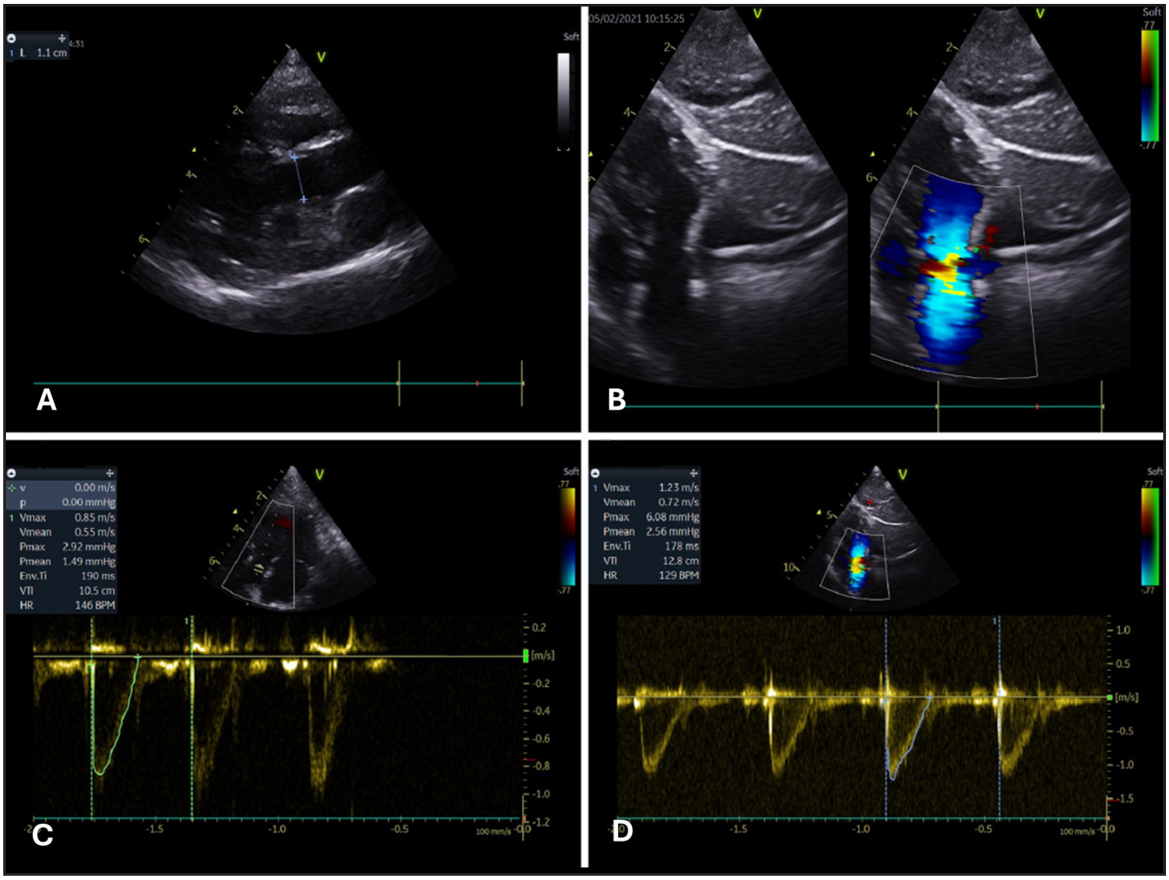


**Figure 1.** A- Parasternal window in the long axis at the level of the aortic valve. B- Subxiphoid window showing the left ventricular outflow tract (LVOT). C- Velocity-time integral (VTI) of the LVOT in an apical 5-chamber window. D- LVOT VTI in subxiphoid window.

## RESULTS

Tables 1 and 2 demonstrate the descriptive analysis of the variables under study, in which the mean, standard deviation (DV), coefficient of variation (CV), 95% confidence interval (95% CI) and minimum and maximum values are presented (Min-Max) of the following variables: left ventricular outflow tract internal diameter (LVOTD), velocity-time integral (VTI), stroke volume (SV), heart rate (HR), cardiac output (CO), weight and age. The FC variable obtained a very high variation value due to its inherent nature for each individual.

Tables 3 and 4 demonstrate the correlations between the 7 variables studied for the volumetric determination of the LVOT in the 5C apical and subxiphoid windows: LVOT, VTI, SV, HR, CO, WEIGHT and AGE. Data analysis showed a strong positive correlation between the variables VTI x LVSD, SV x LVSD, SV x VTI, DC x LVSD, DC x VTI, DC x SV; Weight x LVSD; Weight x VTI; Weight x SV and Weight x CO in both echocardiographic windows. It can be observed that DC x LVSD, SV x LVSD and DC x SV presented correlations greater than 0.9.

VTI, SV and DC were comparable between the 2 groups (5C Apical Window and Subxiphoid) and showed a statistically significant difference ($P < 0.05$). The mean CO at apical 5C was 2.22 ± 1.29 L/min, while that obtained by the subxiphoid was 2.60 ± 1.49 L/min. The mean SV found in the 5C apical was 19.56 ± 12.27 mL, while that obtained in the subxiphoid was 22.82 ± 14.21 mL. The mean VTI found in the 5C apical was 13.97 ± 2.78 cm, while in the subxiphoid it was 16.34 ± 3.30 cm. The values for the subxiphoid window were higher compared to the values found in the 5C apical window (Table 5). Data analysis in a "box plot chart" demonstrated the asymmetry and upper limit of the values of the subxiphoid window variables compared to the apical 5-chamber window (Figures 2 and 3).

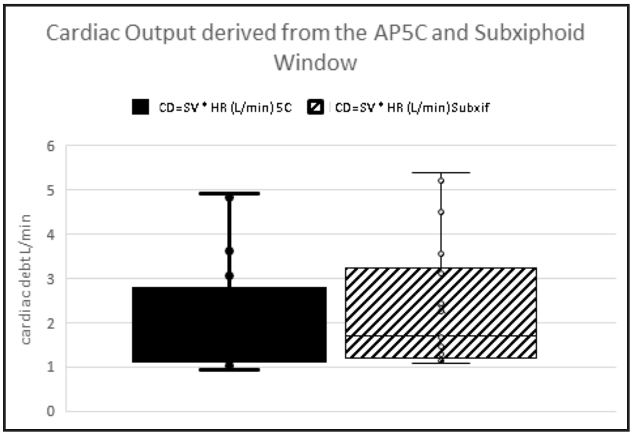


**Figure 2.** Comparative analysis between the cardiac output derived from the 5C Apical and Subxiphoid Window.

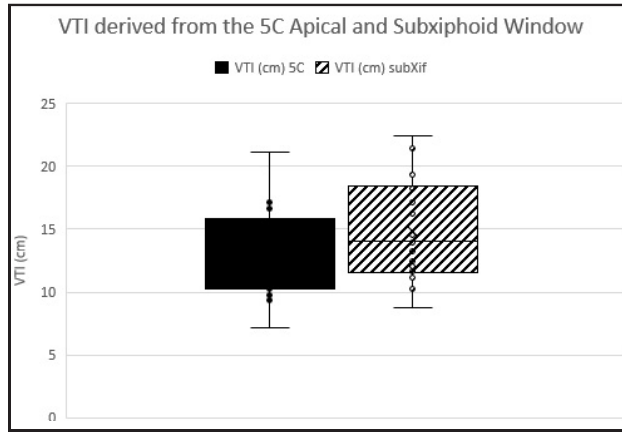


**Figure 3.** Comparative analysis between the aortic VTI derived from the 5C Apical and Subxiphoid Window.

**Table 1.** Statistical description of the variables used in the volumetric determination by the 5C Apical window in healthy dogs.

| Variables | Mean | SD | VC | IC=95% | Min - Max |
|---|---|---|---|---|---|
| LVSD (cm) | 1.27 | 0.27 | 0.07 | 0.19 | 1 - 1.8 |
| VTI (cm) | 13.97 | 2.78 | 7.740 | 1.99 | 9.8 - 17.3 |
| SV (mL) | 19.56 | 12.27 | 150.57 | 8.78 | 7.64 - 44 |
| HR (bpm) | 117.9 | 23.21 | 538.77 | 16.60 | 85 - 173 |
| CD (L/min) | 2.22 | 1.29 | 1.68 | 0.93 | 0.94 - 4.84 |
| Weight (kg) | 13.48 | 8.86 | 78.65 | 6.34 | 3.5 - 20 |
| Age (years) | 9.67 | 2.15 | 4.63 | 1.54 | 5.9 - 13.4 |

LVSD: internal diameter of the left ventricular outflow tract; VTI: velocity - time integral; SV: Stroke Volume; HR: Heart Rate; DC: Cardiac Output; DV: standard deviation; CV: coefficient of variation; CI: confidence interval; Min - Max: minimum - maximum; bpm: beats per minute.

**Table 2.** Statistical description between the variables used in the volumetric determination by the Subxiphoid Window in healthy dogs.

| Variables | Mean | SD | CV | CI=95% | Min - Max |
|---|---|---|---|---|---|
| LVSD (cm) | 1.270 | 0.27 | 0.07 | 0.19 | 1 - 1.8 |
| VTI (cm) | 16.34 | 3.30 | 10.89 | 2.36 | 11.28 - 21.4 |
| SV (mL) | 22.82 | 14.21 | 202.15 | 10.17 | 8.79 - 49 |
| HR (bpm) | 117.90 | 23.21 | 538.76 | 16.60 | 85 - 173 |
| CD (L/min) | 2.60 | 1.49 | 2.23 | 1.06 | 1.08 - 5.39 |
| Weigth (kg) | 13.48 | 8.86 | 78.65 | 6.34 | 3.5 - 20 |
| Age (years) | 9.67 | 2.15 | 4.63 | 1.54 | 5.9 - 13.4 |

LVSD: internal diameter of the left ventricular outflow tract; VTI: velocity - time integral; SV: stroke volume; HR: heart rate; DC: Cardiac Output; SD: standard deviation; CV: coefficient of variation; CI: confidence interval; Min - Max: minimum - maximum.

**Table 3.** Statistical correlation between the variables used in the volumetric determination by the 5C Apical Window in healthy dogs.

| Variables | LVSD (cm) | VTI (cm) | SV (mL) | HR | CO (L/min) | Weight (kg) | Age (years) |
|---|---|---|---|---|---|---|---|
| LVSD (cm) | 1 | | | | | | |
| VTI (cm) | 0.803 | 1 | | | | | |
| SV (mL) | 0.987 | 0.859 | 1 | | | | |
| HR | -0.158 | -0.565 | -0.297 | 1 | | | |
| CO (L/min) | 0.990 | 0.772 | 0.972 | -0.075 | 1 | | |
| Weight (kg) | 0.782 | 0.668 | 0.802 | -0.402 | 0.735 | 1 | |
| Age (years) | 0.060 | -0.077 | 0.045 | -0.068 | 0.029 | 0.254 | 1 |

LVSD: internal diameter of the left ventricular outflow tract; VTI: velocity-time integral; SV: stroke volume; HR: heart rate; CO: cardiac output.

**Table 4.** Statistical correlation between the variables used in the volumetric determination by the Subxiphoid Window in healthy dogs.

| Variables | LVSD (cm) | VTI (cm) | SV (mL) | HR | DC (L/min) | Weight (kg) | Age (years) |
|---|---|---|---|---|---|---|---|
| LVSD (cm) | 1 | | | | | | |
| VTI (cm) | 0.798 | 1 | | | | | |
| SV (mL) | 0.987 | 0.860 | 1 | | | | |
| HR (bpm) | -0.158 | -0.501 | -0.285 | 1 | | | |
| CO (L/min) | 0.989 | 0.785 | 0.972 | -0.059 | 1 | | |
| Weight (kg) | 0.782 | 0.624 | 0.787 | -0.402 | 0.715 | 1 | |
| Age (years) | 0.060 | -0.090 | 0.044 | -0.068 | 0.0147 | 0.254 | 1 |

LVSD: internal diameter of the left ventricular outflow tract; VTI: velocity-time integral; SV: stroke volume; HR: heart rate; CO: cardiac output.

**Table 5.** Comparison between the means of the variables used in the volumetric determination by the 5C Apical Window and Subxiphoid Window in healthy dogs.

| Variables | Apical 5C | Subxiphoid Window |
|---|---|---|
| LVSD (cm) | 1.27 ± 0.27 | 1.270 ± 0.27 |
| VTI (cm) | 13.97 ± 2.78[a] | 16.34 ± 3,30[b] |
| SV (mL) | 19.56 ± 12.27[a] | 22.82 ± 14.21[b] |
| HR (bpm) | 117.9 ± 23.21 | 117.90 ± 23.21 |
| CO (L/min) | 2.22 ± 1.29[a] | 2.60 ± 1.49[b] |
| Weight (kg) | 13.48 ± 8.86 | 13.48 ± 8.86 |
| Age (years) | 9.67 ± 2.15 | 9.67 ± 2.15 |

Different letters indicate a statistically significant difference between the means ($P < 0.05$). LVSD: Inner Diameter of the Left Ventricular Outflow; VTI: velocity-time integral; SV: stroke volume; HR: heart rate; CO: cardiac output.

## DISCUSSION

Echocardiography has been validated in other studies as a reliable technique for determining cardiac output in humans [2,13] and dogs [16,28]. However, there is still a lack of consensus on the influence of flow acquisition techniques on the LVOT and its hemodynamic variables in Veterinary Medicine, in healthy patients and in different pathological conditions, since this flow can be obtained with the transducer in an apical position, subxiphoid /subcostal, parasternal and suprasternal [2,23].

The present study is the 1st in Veterinary Medicine to compare LVOT-derived hemodynamic indices in the apical and subxiphoid windows. Previous studies in dogs have only emphasized the difference in peak velocity and/or time integral velocity of the aortic flow. These cited studies report that the flow velocities derived from subxiphoid windows are superior to the apical region [1,23].

It was observed in the present study that the hemodynamic values obtained through the subxiphoid window were always higher than those obtained through the 5C apical window, with a statistically significant difference. In echocardiography, it is of fundamental importance to have knowledge about the differences in results between different methodologies in obtaining hemodynamic data, in order to avoid clinical errors in the diagnosis and treatment of patients [11].

In a study in Human Medicine, a significant variability of VTI and peak velocity was also found, when comparing different acquisition techniques, referring to these findings the influence of the location of the Doppler sampling on the impact of the resulting velocity [20]. This information corroborates our results, which showed a significant difference in the VTI of the LVOT between the 2 forms of acquisitions, thus directly impacting the other hemodynamic variables evaluated.

One reason for this difference is that the Doppler beam is dependent on alignment with blood flow. A Doppler signal with an intercept angle closer to 0° is preferable to obtain reliable values, because when the angle deviates from zero the velocity will be underestimated [6,18]. Thus, the transducer in subxiphoid position allows for more consistent alignment of the ultrasound beam with aortic blood flow in dogs [23].

CO and SV can be underestimated when VTI is measured with the probe in an apical position. Based on our results, we speculate that measurement of LVOT flow in a subxiphoid position is the preferred method for acquiring more accurate data from CO and SV. However, positioning the transducer close to the xiphoid process and angling it becomes uncomfortable and some dogs do not tolerate it and reluctant to accept it without sedated [1].

Studies performed in humans have suggested that cardiac output and VTI do not correlate with body mass index or weight, reporting that vessel diameter has a greater relevance in the variation of cardiac output [19]. In our studies, the variables that showed the highest correlation value were LVOT and CO in both acquisition methods, thus agreeing with the work reported. However, CO and VTI showed a certain correlation with weight, albeit moderately, similarly to what was observed in healthy children and adolescents, which was also shown that the LVOT VTI was associated with weight in this group of patients [11]. However, this correlation was not seen in children under 1 year of age, where there was independence between VTI and body weight [20].

Previous human studies, the LVOT VTI allows for early identification of cardiogenic shock [25]. Studies carried out in dogs [8] have used VTI as a substitute for VS. This approach eliminates errors in the determination of the LVOT cross-sectional area defined by the formula ϖr2 [8]. In addition, the VTI has also been used in therapeutic guidance regarding fluid responsiveness [26]. Furthermore, the isolated use of the LVOT VTI is considered a quick and easy-to-apply technique that can help in the assessment of hemodynamic status or suspected abnormal function [22].

In the present study, we did not find a correlation between the age of the dogs and the other variables analyzed. This result differs from that described for humans in a study involving individuals aged 16 to 80 years, where cardiac output decreased with advancing age [19]. Some authors justified this decrease in CO by reducing oxygen consumption, decreasing body size and decreasing HR [7]. Thus, studies with large populations are necessary for a more precise investigation regarding the influence of age on the analyzed parameters [11].

HR is an important intrinsic factor in the variability of echocardiographic measurements [14]. This can be affected by many factors, including stress, age, and physical activity. In the present study, the dogs were at rest, in an appropriate environment, and physically restrained by their owners [21]. Previous studies involving animals with chemical restraint have shown a reduction in the influence of stress on HR. However, sedatives and/or anesthetics can influence the other variables of the present study, but this was not the objective of the research [17].

The CO values derived from the 5-chamber apical and subxiphoid window compared gave a mean error of 0.38 L/min, equivalent to 15% of the resulting value. Although there is a significant difference between these 2 techniques, research suggests accepting a new method when there is a difference in the range between 10% and 20% in DC and recommend accepting a maximum limit of 30% difference [10]. However, due to wide variations in their research, this information becomes questionable [31].

In these circumstances, the level of sensitivity and precision of the LVOT flow measurement becomes worrying, since our research demonstrates a variability of hemodynamic profiles between 2 techniques in healthy dogs. Future studies are needed to investigate its application in Veterinary Medicine in different conditions, pathologies and hemodynamic disorders, in addition, studies involving reference data are needed.

## CONCLUSION

The velocity-time integral of the left ventricular outflow tract, stroke volume and cardiac output were significantly higher in the subxiphoid window compared to the 5-chamber apical window. Further studies are needed to standardize the reference of these variables in different echocardiographic windows for more effective monitoring in cases of impossibility of measurement in a given window, benefiting a more accurate assessment and, consequently, more effective results.

MANUFACTURERS

[1]General Electric (GE) Healthcare. Contagem, MG, Brazil.

[2]GraphPad Software. San Diego, CA, USA.

***Ethical approval*.** The protocols used in this work were approved by the Ethics Committee on Animal Experimentation-CEEA/UFPI, under No. 652/2020.

***Declaration of interest*.** The authors have declared no conflict of interests. The authors alone are responsible for the content and writing of the paper.

**REFERENCES**

1 **Abbott J.A. & MacLean H.N. 2003.** Comparison of Doppler-derived peak aortic velocities obtained from subcostal and apical transducer sites in healthy dogs. *Veterinary Radiology and Ultrasound*. 44(6): 695-698. DOI: 10.1111/j.1740-8261.2007.00299.x.

2 **Aslan N., Yildizdas D., Horoz O.O., Coban Y., Demir F., Erdem S. & Sertdemir Y. 2020.** Comparison of cardiac output and cardiac index values measured by critical care echocardiography with the values measured by pulse index continuous cardiac output (PiCCO) in the pediatric intensive care unit preliminary study. *Italian Journal of Pediatrics*. 46(1): 1-8. DOI: 10.1186/s13052-020-0803-y.

3 **Baron S.B. & Comess K.A. 1990.** Doppler echocardiography. Role in emergency diagnosis of cardiac valve disease. *Postgraduate Medicine*. 87(6): 85-98. DOI: 10.1080/00325481.1990.11716333.

4 **Beigel R., Cercek B., Arsanjani R. & Siegel R.J. 2014.** Echocardiography in the use of noninvasive hemodynamic monitoring. *Journal Critical Care*. 29(1): 1-8. DOI: 10.1016/j.jcrc.2013.09.003.

5 **Blanco P. 2020.** Rationale for using the velocity–time integral and the minute distance for assessing the stroke volume and cardiac output in point-of-care settings. *The Ultrasound Journal*. 12(21): 1-9. DOI: 10.1186/s13089-020-00170-x.

6 **Boon J.A. 2011.** Evaluation of size, function and hemodynamics. In: Boon J. (Ed). *Veterinarian Echocardiography*. Chichester: Wiley-Blackwell, pp.153-267.

7 **Brandfonbrener M., Landdowne M. & Shock N.W. 1955.** Changes in cardiac output with age. *Circulation*. 12(4): 557-566. DOI: 10.1161/01.cir.12.4.557.

8 **Bucci M., Rabozzi R., Guglielmini C. & Franci P. 2017.** Respiratory variation in aortic blood peak velocity and caudal vena cava diameter can predict fluid responsiveness in anesthetised and mechanically ventilated dogs. *The Veterinary Journal*. 227(1): 30-35. DOI: 10.1016/j.tvjl.2017.08.004.

9 **Buchanan J.W. 2013.** The history of veterinary cardiology. *Journal of Veterinary Cardiology*. 15(1): 65-85. DOI: 10.1016/j.tvjl.2017.08.004.

10 **Critchley L.A. & Critchley J.A. 1999.** A meta-analysis of studies using bias and precision statistics to compare cardiac output measurement techniques. *Journal of Clinical Monitoring and Computing*. 15(2): 85-91. DOI: 10.1023/a:1009982611386.

11 **Díaz A., Zócalo Y., Cabrera-Fischer E. & Bia D. 2018.** Reference intervals and percentile curve for left ventricular outflow tract (LVOT), velocity time integral (VTI), and LVOT-VTI- derived hemodynamic parameters in healthy children and adolescents: Analysis of echocardiographic methods association and agreement. *Echocardiography*. 35(12): 2014-2034. DOI: 10.1111/echo.14176.

12 **Gaspar A., Azevedo P. & Roncon J.R. 2018.** Non-invasive hemodynamic evaluation by Doppler echocardiography. *Brazilian Journal of Intensive Care*. 30(3): 385-393. DOI: 10.5935/0103-507X.20180055.

13 **Irigoyen J.L., Corral J.M., Zelaya I.O., Muñoz G.M., Alcaide V.B., Saera M.B. & Lujan C.V. 2015.** Accuracy of cardiac output estimations by transthoracic echocardiography compared with an accepted method of thermodilution, the pulmonary artery catheter, in the critically ill patients. *Experimental Intensive Care Medicine*. 3(1): 1-2. DOI: 10.1186/2197-425X-3-S1-A598.

14 **Jozwiak M., Mercado P., Teboul J.L., Benmalek A., Gimenez J., Dépret F., Richard C. & Monnet X. 2019.** What is the lowest change in cardiac output that transthoracic echocardiography can detect? *Critical Care*. 23(1): 1-10. DOI: 10.1007/s10877-019-00330-y.

15 **Lang R.M., Badano L.P., Mor-Avi V., Afilalo J., Armstrong A., Ernande L., Flachskampf F.A., Foster E., Goldstein S.A., Kuznetsova T., Lancellotti P., Muraru D., Picard M.H., Rietzschel E.R., Rudski L., Spencer K.T., Tsang W. & Voigt J.U. 2015.** Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *Journal of the American Society Echocardiography*. 28(1): 1-39. DOI: 10.1093/ehjci/jev014.

16 **LeBlanc N.L., Scollan K.F. & Stieger-Vanegas S.M. 2017.** Cardiac output measured by use of electrocardiogram-gated 64-slice multidector computed tomography, echocardiography, and thermodilution in healthy dogs. *American Journal of Veterinary Research*. 78(7): 818-827. DOI: 10.2460/ajvr.78.7.818

17 **Lopes P.C., Sousa M.G., Camacho A.A., Carareto R., Nishimori C.T., Santos P.S. & Nunes N. 2010.** Comparison between two methods for cardiac output measurement in propofol -anesthetized dogs: thermodilution and Doppler. *Veterinary Anaesthesia and Analgesia*. 37(5): 401-408. DOI: 10.1186/s12917-017-1227-9.

18 **Mercado P., Maizel J., Beyls C., Titeca- Beauport D., Joris M., Kontar L., Riviere A., Bonef O., Soupison T., Tribouilloy C., Cagny B. & Slama M. 2017.** Transthoracic echocardiography: an accurate and precise method for estimating cardiac output in the critically ill patient. *Critical Care*. 21(1): 1-8. DOI: 10.1186/s13054-017-1737-7.

19 **Mowat D.H., Haites N.E. & Rawles J.M. 1983.** Aortic blood velocity measurement in healthy adults using a simple ultrasound technique. *Cardiovascular Research*. 17(2): 75-80. DOI: 10.1093/cvr/17.2.75.

20 **Navaratnam M., Punn R., Ramamoorthy C. & Tacy T.A. 2017.** LVOT-VTI is a Useful Indicator of Low Ventricular Function in Young Patients. *Pediatric Cardiology*. 38(6): 1148-1154. DOI: 10.1007/s00246-017-1630-9.

21 **Ortmeyer H.K. & Katzel L.I. 2020.** Effects of Proximity between Companion Dogs and Their Caregivers on Heart Rate Variability Measures in Older Adults: A Pilot Study. *International Journal of Environmental Research and Public Health*. 17(8): 1-12. DOI: 10.3390/ijerph17082674.

22 **Pees C., Glagau E., Hauser J. & Michel- Behnke I. 2013.** Reference values of aortic flow velocity integral in 1193 healthy infants, children, and adolescents to quickly estimate cardiac stroke volume. *Pediatric Cardiology*. 34(5): 1194-2000. DOI: 10.1007/s00246-012-0628-6.

23 **Riesen S.C., Doherr M.G. & Lombard C.W. 2007.** Comparison of Doppler-derived aortic velocities obtained from various transducer sites in healthy dogs and cats. *Veterinary Radiology Ultrasound*. 48(6): 570-573. DOI: 10.1111/j.1740-8261.2007.00299.x.

24 **Steeds R.P. 2011.** Echocardiography: frontier imaging in cardiology. *The British Journal of Radiology*. 84(3): 237-245. DOI: 10.1259/bjr/77730594.

25 **Tan C., Rubenson D., Srivastava A., Mohan R., Smith M.R, Billick K., Bardarian S. & Heywood J.T. 2017.** Left ventricular outflow tract velocity time integral outperforms ejection fraction and Doppler-derived cardiac output for predicting outcomes in a select advanced heart failure cohort. *Cardiovascular Ultrasound*. 15(1): 18. DOI: 10.1186/s12947-017-0109-4.

26 **Teixeira-Neto F.J. & Valverde A. 2021.** Clinical Application of the Fluid Challenge Approach in Goal-Directed Fluid Therapy: What can we learn from human studies? *Frontiers in Veterinary Science*. 8(1): 1-24. DOI: 10.3389/fvets.2021.701377.

27 **Thomas W.P., Gaber C.E., Jacobs G.J., Kaplan P.M., Lombard C.W., Moise N.S. & Moses B.L. 1993.** Recommendations for standards in transthoracic two-dimensional echocardiography in the dog and cat. Echocardiography Committee of the Specialty of Cardiology, American College of Veterinary Internal Medicine. *Journal Veterinary Internal Medicine*. 7(4): 247-252. DOI: 10.1111/j.1939-1676.1993.tb01015.x.

28 **Uehara Y., Koga M. & Takahashi M. 1995.** Determination of cardiac output by echocardiography. *The Journal of Veterinary Medical Science*. 57(3): 401-407.

29 **Uemura K., Kawada T., Inagaki M. & Sugimachi M. 2013.** A minimally invasive monitoring system of cardiac output using aortic flow velocity and peripheral arterial pressure profile. *Anesthesia & Analgesia*. 116(5): 1006-1017. DOI: 10.1292/jvms.57.401.

30 **Vinayagam D., Patey O., Thilaganathan B. & Khalil A. 2017.** Cardiac output assessment in pregnancy: comparison of two automated monitors with echocardiography. *Ultrasound Obstetrics & Gynecology*. 49(1): 32-38. DOI: 10.1002/uog.15915.

31 **Wetterslev M., Møller-Sørensen H., Johansen R.R. & Perner A. 2016.** Systematic review of cardiac output measurements by echocardiography vs. thermodilution: the techniques are not interchangeable. *Intensive Care Medicine*. 42(8): 1223-1233. DOI: 10.1007/s00134-016-4258.