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# Técnicas ecocardiográficas para avaliação da pressão da artéria pulmonar

# Echocardiographic techniques for assessing pulmonary artery pressure

# Técnicas ecocardiográficas para la evaluación de la presión de la arteria pulmonar

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**Tamyris Beluque**
ORCID: https://orcid.org/0000-0003-2858-0310
Paulista State University, Brazil
E-mail: tamyrisbeluque@gmail.com
**Bruna Natali da Costa**
ORCID: https://orcid.org/0000-0002-4813-7853
Federal University of Paraná, Brazil
E-mail: mvbrunacosta@gmail.com
**Beatriz de Carvalho Pato Vila**
ORCID: https://orcid.org/0000-0002-7409-3655
Paulista State University, Brazil
E-mail: beatriz.pato@gmail.com
**Vinícius Bentiglóvio Costa Silva**
ORCID: https://orcid.org/0000-0002-0232-272X
Federal University of Paraná, Brazil
E-mail: viniciusbcsilva@gmail.com
**Marlos Gonçalves Sousa**
ORCID: https://orcid.org/0000-0003-1367-9828
Federal University of Paraná, Brazil
E-mail: marlos98@ufpr.br

## Resumo

O presente trabalho tem como objetivo realizar uma análise dos métodos indiretos da avaliação da pressão da artéria pulmonar com base na literatura científica. Por meio de levantamento bibliográfico, artigos científicos foram selecionados conforme a sua relevância para o tema. A avaliação da pressão da artéria pulmonar permite inferir se o paciente apresenta hipertensão arterial pulmonar (HAP), a qual está associada a um prognóstico ruim em cães. O exame padrão é a cateterização da artéria pulmonar, porém este método não tem

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sido utilizado na rotina da medicina veterinária porque o quadro clínico do animal comumente não permite a sedação e por se tratar de um procedimento oneroso. O diagnóstico da HAP em pequenos animais por meio da ecodopplercardiografia pode ser obtido com a avaliação da regurgitação da valva tricúspide ou pulmonar, características subjetivas e mensuração do tempo de aceleração (TA) e relação entre o tempo de aceleração e o tempo de ejeção do fluxo pulmonar (TA:TE), relação entre a artéria pulmonar e a veia pulmonar, distensibilidade da artéria pulmonar direita (RPAD), e ainda por avaliação da função do ventrículo direito, principalmente o índice de TEI e o strain. O objetivo desta revisão foi demonstrar as principais técnicas ecocardiográficas para estimar HAP, com o intuito de contribuir com o cardiologista no diagnóstico da HAP. Todas as técnicas apresentam fatores positivos e negativos, porém é importante ressaltar que não existe uma técnica ideal, e a forma mais assertiva de se chegar ao diagnóstico é associando as diversas técnicas.
**Palavras-chave:** Hipertensão Arterial Pulmonar; Índice de Distensibilidade da Artéria Pulmonar Direita; Regurgitação da Pulmonar; Regurgitação da Tricúspide.

**Abstract**

This paper aims to perform an analysis of the indirect methods of pulmonary artery pressure assessment based on the scientific literature. Through bibliographic survey, scientific articles were selected according to their relevance to the theme.The assessment of pulmonary artery pressure allows to infer whether the individual has pulmonary arterial hypertension (PAH), which is associated with a poor prognosis in dogs diagnosed with mitral valve degeneration. The standard examination is pulmonary artery catheterization, but this method has not been used in routine veterinary medicine because the clinical status of the animal usually does not allow sedation and it is a costly procedure. The diagnosis of PAH in small animals through Doppler echocardiography can be obtained by evaluating the regurgitation of the tricuspid or pulmonary valve, subjective characteristics and measurement of the acceleration time (AT) and the acceleration time-to-ejection time ratio of pulmonary artery (AT:ET), pulmonary artery-to-pulmonary vein ratio, distensibility of the right pulmonary artery (RAPD), and assessment of right ventricular function, especially TEI index and strain. The aim of this review was to demonstrate the main echocardiographic techniques to estimate PAH, with the intention of contributing to the cardiologist in the diagnosis of PAH. All techniques have positive and negative factors however, it is important to emphasize that there is no ideal technique, and the most assertive way to arrive at the diagnosis is to associate the different techniques.

**Keywords:** Pulmonary Arterial Hypertension; Pulmonary Regurgitation; Right Pulmonary Artery Distensibility Index; Tricuspid Regurgitation.

**Resumen**

Este artículo tiene como objetivo realizar un análisis de los métodos indirectos de evaluación de la presión de la arteria pulmonar con base en la literatura científica. A través de la encuesta bibliográfica, los artículos científicos se seleccionaron de acuerdo con su relevancia para el tema. La evaluación de la presión de la arteria pulmonar permite inferir si el individuo tiene hipertensión arterial pulmonar (HAP), que se asocia con un mal pronóstico en perros diagnosticados con degeneración de la válvula mitral. El examen estándar es el cateterismo de la arteria pulmonar, pero este método no se ha utilizado rutinariamente en medicina veterinaria porque el estado clínico del animal generalmente no permite la sedación y es un procedimiento costoso. El diagnóstico de HAP en animales pequeños a través de la ecocardiografía Doppler puede obtenerse evaluando la regurgitación de la válvula tricúspide o pulmonar, las características subjetivas y la medición del tiempo de aceleración (AT) y la relación tiempo de aceleración / tiempo de expulsión de la arteria pulmonar (TA:TE), relación arteria pulmonar-vena pulmonar, distensibilidad de la arteria pulmonar derecha (RAPD) y evaluación de la función ventricular derecha, especialmente el índice TEI y strain. El objetivo de esta revisión fue demostrar las principales técnicas ecocardiográficas para estimar la HAP, con la intención de ayudar al cardiólogo en el diagnóstico de la HAP. Todas las técnicas tienen factores positivos y negativos, sin embargo es importante enfatizar que no existe una técnica ideal, y la forma más asertiva de llegar al diagnóstico es asociar las diferentes técnicas.

**Palabras clave:** Hipertensión Arterial Pulmonar; Regurgitación Pulmonar; Índice de Distensibilidad de la Arteria Pulmonar Derecha; Regurgitación Tricuspídea.

## 1. Introduction

The interaction among vascular resistance, post-capillary pressure and blood flow directly interferes with pulmonary arterial pressure (Stepien, 2009), whose evaluation allows to infer if the individual has pulmonary hypertension, an important negative predictor of survival in dogs naturally affected by myxomatous degeneration of the mitral valve (Borgarelli et al., 2015).

Pulmonary arterial hypertension is characterized by an abnormal and persistent increase in pressure (Stepien, 2009) above 31.4 mmHg (Kellihan & Stepien, 2010), and may

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be secondary to heart diseases affecting the left side of the heart, called post-capillary hypertension, or to respiratory diseases, as in the case of pre-capillary hypertension. The presence of pulmonary hypertension in dogs diagnosed with mitral valve degeneration is associated with a poor prognosis, and the pressure gradient of tricuspid regurgitation greater than 55 mmHg, suggesting moderate hypertension, was a predictor of death. It was also demonstrated the predisposition of dogs, in a more advanced stage of valve disease, to develop pulmonary hypertension (Borgarelli et al., 2015).

In medicine, the standard examination is pulmonary artery catheterization, but this method has not been used in routine veterinary medicine because the clinical status of the animal commonly does not allow sedation (Kellihan & Stepien, 2010).

The diagnosis of pulmonary hypertension in small animals involves the presence of clinical signs, in more advanced stages; and complementary diagnoses such as laboratory tests, electrocardiography, chest X-ray and echocardiogram (Kellihan & Stepien, 2010), mainly through the quantification of tricuspid and pulmonary valve regurgitation (Visser, Im, Johnson, & Stern, 2016), which allows estimation of pulmonary arterial pressure. Although widely used, this method may not be ideal because valve insufficiency may be absent or difficult to measure (Visser et al., 2016), so the diagnosis may be based on other echocardiographic findings (Kellihan & Stepien, 2010).

Much has been studied regarding the best way to evaluate pulmonary artery pressure through Doppler echocardiography, so the present review aims to demonstrate the main techniques with the intention of contributing to the veterinary cardiologist in the choice of technique for the diagnosis of hypertension pulmonary.

This paper aims to perform an analysis of the indirect methods of pulmonary artery pressure assessment based on the scientific literature, demonstrating the main echocardiographic techniques to estimate PAH, with the intention of contributing to the cardiologist in the diagnosis of PAH. Through bibliographic survey, scientific articles were selected according to their relevance to the theme.

## 2. Methodology

The methodology used was based on a qualitative / analytical research through bibliographic surveys on indirect methods of pulmonary artery pressure assessment.

The bibliographic analysis included international indexed journals and books. These underwent a subjective analysis and were selected according to their relevance to the theme.

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## 3. Results and discussion

### 3.1 Tricuspid regurgitation

Tricuspid regurgitation (RT) is present in the majority of patients with pulmonary hypertension, ranging from mild to severe. This regurgitation may be secondary to annular stretching or changes in right ventricular (RV) geometry. In the absence of RV outlet obstruction, the systolic pulmonary artery pressure (PAP) is equal to the RV systolic pressure. Through Bernoulli's equation, the RV systolic pressure can be estimated using the velocity of the RT jet (Boon, 2011). The modified Bernoulli equation is used to calculate the pressure gradient between two areas of the heart. The smaller the orifice through which the reflux will pass, the greater the pressure differential will be and the higher the blood velocity (Boon, 2011).

Modified Bernoulli Equation: Pressure gradient (mmHg) = 4 x blood velocity distal to the orifice$^2$ (m/s)

The peak of systolic TR velocity and estimated RV systolic pressure are used to classify the severity of pulmonary arterial hypertension (HP), as described in Table 1 (Kellihan & Stepien, 2010).

Table 1. Severity of pulmonary hypertension according to the peak velocity of the TR and the systolic gradient of the TR. Adapted from Kellihan and Stepien (2010). TR = Tricuspid regurgitation.

| | Mild | Moderate | Severe |
|---|---|---|---|
| **Systolic TR velocity peak (m/s)** | ≥2.8-<3.5 | 3.5-4.3 | >4.3 |
| **Systolic TR gradient (mmHg)** | ≥31.4-<50 | 50-75 | >75 |

Soydan et al. (2015) performed acute embolization with multiple injections of polyvinyl alcohol microspheres in 14 Beagles, and compared the invasively estimated PAP by catheterization of the RV with PAP estimated by the echocardiographic image of the TR. They also assessed the accuracy of adding right atrial pressure (RAP) in the Bernoulli equation. Significantly positive correlation was observed between the noninvasive estimates and the invasive measures of PAP, but the relation between the predicted and actual values is highly variable. The higher the PAP measured by catheterization, the non-invasive PAP variance increases even more. This imprecision of PAP measurement from TR has also been reported in many human studies (Yock & Popp, 1984; Brecker, Gibbs, Fox, Yacoub, & Gibson, 1994; Fisher et al., 2009; Janda, Shahidi, Gin, & Swiston, 2011; Rich, Shah, Swamy, Kamp, & Rich, 2011). The highest correlation coefficients for predicting PAP were observed when RAP estimates were included; however, the actual difference in correlation was insignificant, suggesting little additional value in the inclusion of RAP estimates in the study (Soydan et al., 2015).

The difficulty in obtaining an ideal peak of systolic blood pressure can also be attributed to the patient's low adherence to the echocardiographic procedure, the poor image quality secondary to dyspnea and right ventricular dysfunction (Stepien, 2009). Although the systolic velocity gradient of TR peak is an echocardiographic indicator of PAP in dogs, the situational limitations of this estimation during the examination should be considered and, whenever possible, additional information should be collected to aid in PAP evaluation and diagnosis and classification PH (Kellihan & Stepien, 2010). It is important to emphasize that, although frequent, TR is not present in all cases of pulmonary hypertension, favoring the appearance of false negatives.

**3.2 Pulmonar Regurgitation**

In the absence of tricuspid valve regurgitation, pulmonary valve regurgitation may aid in the diagnosis of pulmonary hypertension (Kellihan & Stepien, 2010).

Diastolic and mean arterial pressure of the pulmonary artery can be estimated by measuring the velocity of pulmonary artery regurgitation, which occurs during diastole. The pressure gradient difference between the right ventricle and the pulmonary artery can be calculated using the modified Bernoulli equation (Kellihan & Stepien, 2010). The rate of pulmonary insufficiency above 2.2 m / s or greater, with a gradient of 19 mmHg or higher, may indicate pulmonary arterial hypertension (Kellum & Stepien, 2007).

In dogs with induced acute pulmonary hypertension, increased values of mean and diastolic pulmonary pressure were observed through pulmonary regurgitation, as well as high values of systolic pressure measured by the regurgitation jet of the tricuspid valve (Soydan et al. 2015). Although the techniques showed good sensitivity and specificity, all the values found by the pulmonary regurgitation gradient were underestimated when compared to the actual values obtained with pulmonary artery catheterization (Soydan et al. 2015). In addition, human studies have shown that this technique is less sensitive to tricuspid regurgitation, so it should not be the first choice when pulmonary hypertension is suspected, but it may be a good alternative in the absence of atrioventricular regurgitation (Lanzarini, Fontana, Lucca, Campana, & Klersy, 2002).

**3.3 Systolic Pulmonary Artery Flow: Qualitative Evaluation**

The qualitative evaluation of the pulmonary flow can estimate the severity of pulmonary hypertension in dogs and humans (Kellum & Stepien et al., 2007). The flow can be classified into three types (Kellum & Stepien et al., 2007; Boon, 2011):

Type I: Associated with the absence of pulmonary hypertension, it is characterized by symmetry, the point of maximum velocity will be located in the middle of the flow, giving the "dome" format, with similar acceleration and deceleration time.

Type II: Associated with mild to moderate pulmonary hypertension. The deceleration time is longer than the acceleration time, the speed peak occurs earlier.

Type III: Associated with severe pulmonary hypertension. The deceleration time is also longer than the acceleration time, as in type II, but there is a notch during the deceleration, possibly caused by the "flow reversal".

In one study, all the dogs that presented notch in the pulmonary flow were found to have pulmonary hypertension, with a sensitivity of 76% (Visser et al., 2016).

**3.4 Right ventricular systolic time intervals**

In the absence of tricuspid or pulmonary regurgitation, or even in cases of difficult alignment, it may be difficult to obtain the value of pulmonary arterial pressure (Schoeber & Baade, 2006). One way out of this would be to evaluate the pressure by measurements in the pulmonary flow.

The right ventricular systolic time intervals are represented by the acceleration time (AT), ejection time (ET), AT: ET and pre-ejection period; and may be a tool for the diagnosis of pulmonary hypertension (Kellum & Stepien et al., 2007). Associating these values with the pulmonary flow, we can infer about the right ventricular overload.

Schober and Baade (2006) evaluated pulmonary pressure through tricuspid regurgitation in healthy dogs and dogs with pulmonary hypertension. Acceleration time and ejection time measurements were performed, and the relationship between the two was applied. The authors did not find a significant difference in the ET values between the groups, but there was a significant decrease in the AT and in the AT: ET ratio in the group with pulmonary hypertension, and the group that presented the highest rate of tricuspid regurgitation also had the lowest values for the acceleration time and its relation over the ejection time. Similar results were observed in the work of Visser et al. (2016): the more severe the pulmonary hypertension, the lower the AT value and the AT: ET ratio.

This technique has brought favorable results, however it is worth remembering that the assessment of pulmonary hypertension by Doppler has its limitations, as it depends on the operator's experience and the adequate alignment of the image for a correct acquisition of the pulmonary flow at its maximum speed, allowing high rate of errors about the value of pulmonary arterial pressure (Visser et al., 2016).

### 3.5 Right Pulmonary Artery Distensibility

The PH causes distension of the artery wall, causing a stiffening of the proximal pulmonary arteries (Gan et al., 2007). Studies in humans suggest that the non-invasive index of pulmonary artery distensibility by cardiac magnetic resonance imaging may be a useful tool in the assessment of pulmonary artery (PA) stiffness in patients with PH (Jardim et al., 2007; Kang et al., 2011). In humans, distensibility of the pulmonary artery is a good predictor of mortality (Gan et al, 2007).

The RPAD index is a valuable method for assessing the presence and severity of pulmonary hypertension in normal and heartworm dogs, and in humans. The first study to evaluate the distensibility of the right pulmonary artery (RPAD) was aimed at detecting and evaluating pulmonary hypertension in dogs with heartworm disease. This technique was shown to be simple and easily reproducible, showing a strong correlation with invasive HP pressure, demonstrating its diagnostic potential in dogs (Venco, Mihaylova, & Boon, 2014).

The validation of RPAD evaluation in dogs was performed by Visser et al. (2016). This RPAD index allows the evaluation of dogs with PH by 2D echocardiography, and is mainly used when tricuspid regurgitation and / or pulmonary insufficiency is absent or difficult to measure by Doppler (Venco et al., 2014; Visser et al., 2016).

The images are acquired by an optimized view of the parasternal window directly on the short axis of the heart base. The RPAD index represents the percentage variation between the diastolic diameter of the right pulmonary artery (RPA) (Q wave) by the maximum systolic diameter of the RPA (broader T-wave deflection or from the beginning to the middle of systole), and is calculated according to with the following formula (Visser et al., 2016):

RPAD index = ([RPAS - RPAD] / RPAS) x 100

When the RPDA index is compared with the MPA: Ao, AT and AT: ET, it presents a higher correlation with the tricuspid regurgitation pressure gradient (TRPG), and has a more precise cutoff point (value less than 29, 5%, sensitivity 0.84, specificity 0.95) to predict

TRPG> 50 mmHg. To predict TRPG> 36 mmHg its sensitivity is 0.74 and the specificity is 0.91. It has also been shown to be an index of good repeatability, presenting a variation between intra and inter-observer ≤13% (Visser et al., 2016). It is a simple method of evaluation of PH, possible to be evaluated in the absence of tricuspid and / or pulmonary regurgitation, and does not require echocardiographic Doppler.

**3.6 Main Pulmonary Artery and Aortic Artery Ratio**

Another predictive index of PH is the ratio of the main pulmonary artery and aortic artery (MPA: Ao), obtained by the ratio between the internal dimensions of the main pulmonary artery (MPA) in the diastole and the ascending aorta (Ao) on the short axis , by the 2D method (Serres et al., 2007). Its specificity is 0.94 and its sensitivity is 0.74 (Visser et al., 2016). The ratio in normal dogs is 0.8-1.15 of the pulmonary artery / aorta (Serres et al., 2007).

**3.7 Pulmonary Artery and Pulmonary Vein Ratio**

As the phase of the cardiac cycle, the diameter of the veins and pulmonary arteries change. It is possible to measure the diameters of these vessels by transthoracic echocardiography in the short axis views modified to the right side, obtaining images in the M or 2D mode, presenting a good repeatability for both methods (Merveille et al., 2015; Birettoni et al., 2016). For the evaluation of pulmonary artery (AP) and pulmonary veia (PV), or M mode allows melhores informações on as alterações phasic deses glasses during or cardiac cycle. The measurement can be carried out according to the electrical events (peak of QRS and end of wave T) or mechanical (maximum and minimum diameter), both in artery and vein, and no difference between the two methods (Birettoni et al., 2016). The normal relationship between pulmonary vein and pulmonary artery is approaching 1.0, and a diastole is maintained (Merveille et al., 2015; Birettoni et al., 2016).

In dogs with degenerative mitral valve disease this ratio increases according to the class of heart failure, being an index of pulmonary venous congestion. The established cut-off value is 1.7 in two-dimensional mode to differentiate dogs with and without CHF (Merveille et al., 2015).

**3.8 TEI index**

The TEI index was established for the non-invasive quantification of RV function in patients with primary pulmonary arterial hypertension (Tei et al., 1996). This measure was proposed as an alternative to the functional evaluation of the RV, which until then was performed by the subjective analysis of the analyzer or through means of invasive methods, such as pulmonary catheterization (Salgado, Albanesi Filho, Castier, & Bedirien, 2004). The value of this index is obtained through the sum of the isovolumetric contraction time (IVCT) with the isovolumetric relaxation time (IVRT), divided by the ejection time (ET) (Tei et al., 1996). The IVCT and the ET reflect the ventricular systolic function, while the IVRT reflects the ventricular diastolic function, representing the overall myocardial performance (Salgado et al., 2004).

In a recent study, Nakamura et al. (2016) found an association between the RV TEI index and the systolic PAP. It was also verified a strong correlation of this indicator with HP severity in dogs with mitral valvular degenerative disease (MVDD), as well as the prognostic value of this indicator. The RV TEI index is strongly related to early death in dogs with MVDD, showing an independent mortality indicator more sensitive than other right-sided echocardiographic variables, such as the AT:ET of pulmonary artery, systolic PAP, RT velocity (Nakamura et al., 2016). Other studies have also demonstrated the correlation between TEI index and pulmonary artery pressure, showing the importance of the technique to quantify the severity of pulmonary hypertension (Teshima et al, 2006; Morita et al., 2017).

This parameter has some advantages over other measurements, such as not being significantly affected by heart rate (in the case of TDI obtained by TDI), body weight, age or tricuspid regurgitation (Tei et al., 1996; Baumwart, Meurs, & Bonagura, 2005; Teshima et al., 2006). No tricuspid regurgitation was found in 31% of the human patients with pulmonary hypertension confirmed by catheterization (Capomolla et al., 2000). In dogs with DMVM, tricuspid regurgitation is not achieved in 22% of cases, while the RV TEI index is accessible to all dogs when obtaining the images of the inflow and outflow of the RV (Nakamura et al., 2016).

**3.9 Strain**

The strain is defined as the percentage of shortening of a region of interest, relative to its original length, and is expressed as a negative percentage (Reisner et al., 2004). This technique can be implemented to assess regional and overall RV function as well as the impact of RV pressure overload on ventricular interdependence and relative LV performance. The analysis of ventricular tension and torsion is an easily obtained, cost-effective, objective, angle-independent and non-invasive technique. (Bossone et al., 2013).

Morita et al. (2017) conducted a study inducing PAP increase in Beagles by administering an analog of thromboxane A2, which induces pulmonary artery constriction. It was found that the RV free wall longitudinal strain is impaired under the pressure overload condition, being an independent predictor of the mean PAP and peripheral vascular resistance. A study in humans with pre-capillary HP also demonstrated the correlation between PAH severity and the degree of RV strain reduction (Puwanant et al., 2010).

This method has acceptable repeatability and reproducibility, as well as the ability to assess global and regional myocardial function, but requires excellent 2D image quality with clear visualization of myocardial borders, as well as the necessary and time-consuming post-processing analysis (Visser, 2017). It is plausible to consider that the accomplishment of this technique requires a device of ecodopplercardiografia with excellent quality of image and with adequate software, making difficult the accomplishment of the strain by great part of the cardiologists in the routine, although widely used in the research.

## 4. Conclusion

The gold standard for measuring pulmonary pressure is catheterization, but because it is an invasive method, it is not widely used in veterinary medicine. Echocardiographic indexes are used in an attempt to estimate the value of pulmonary artery pressure.

There are several echocardiographic techniques to estimate pulmonary artery hypertension, and these diagnostic tools alone have their limitations and advantages. The combination of techniques for a definite definitive diagnosis of pulmonary arterial hypertension is necessary.

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**Porcentagem de contribuição de cada autor no manuscrito**

Tamyris Beluque – 20%

Bruna Natali da Costa – 20%

Beatriz de Carvalho Pato Vila – 20%

Vinícius Bentiglóvio Costa Silva – 20%

Marlos Gonçalves Sousa – 20%