

My Approach To Echocardiographic Assessment In Pulmonary Hypertension

Como eu Faço a Avaliação Ecocardiográfica na Hipertensão Pulmonar

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Pulmonary hypertension (PH) is a syndrome with a high worldwide prevalence characterized by increased pulmonary circulation pressure that progressively leads to vascular bed and right ventricle component remodeling.¹

The PH diagnosis is suspected based on clinical signs/symptoms and echocardiographic findings, but it is confirmed only by direct and invasive measurements during right heart catheterization showing a mean pulmonary artery pressure (mPAP) > 20 mmHg. Treatment aims to alleviate symptoms

and delay progression to the final disease stage, which presents irreversible micro- and macrovascular changes and right ventricular dysfunction. A delayed diagnosis changes the natural course of the disease, increasing morbidity and mortality.^{2,3}

From clinical and hemodynamic points of view, PH can be classified into five groups (Figure 1 e Table 1):^{4,5}

Echocardiography plays a fundamental role in the diagnostic screening of PH and in the assessment of right ventricular systolic function.

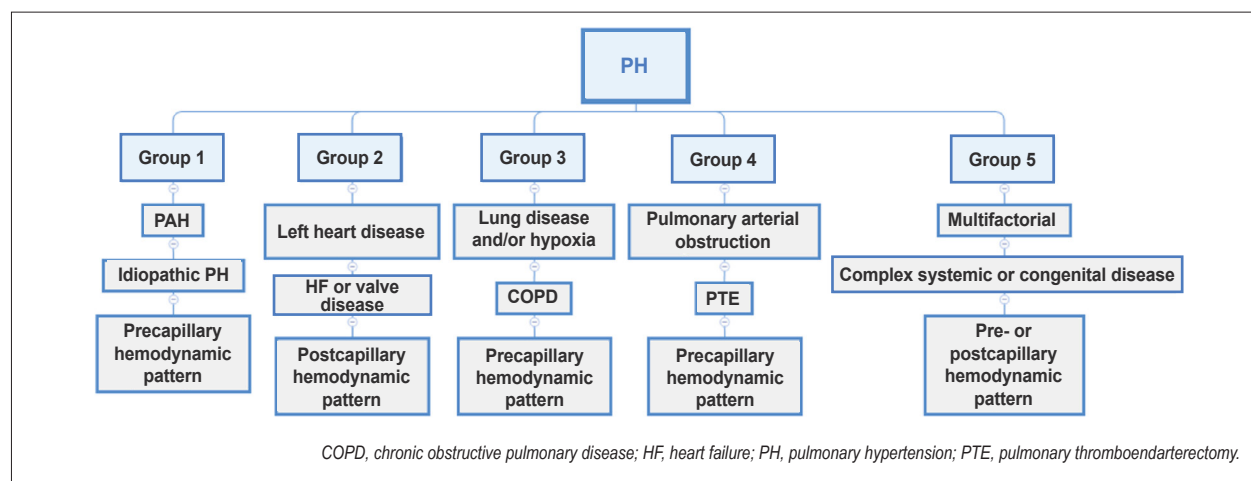


Figure 1 – Haemodynamic classification of PH Classificação hemodinâmica da Hipertensão pulmonar.

Keywords

Hypertension, Pulmonary; Diagnosis; Echocardiography.

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Table 1 – Clinical and hemodynamic classification of pulmonary hypertension groups.

Group	Sub-group	Clinical presentation	Hemodynamics
I	PAH	Idiopathic PAH Hereditary PAH PAH associated with connective tissue disease, HIV, portal hypertension, congenital heart disease, schistosomiasis PAH CCB responders Pulmonary capillary hemangiomatosis, pulmonary veno-occlusive disease Persistent PH of the newborn	Dyspnea, syncope, jugular stasis, peripheral edema Specific signs of connective tissue, liver, and HIV disease Echocardiographic signals limited to the right chambers
II	PH secondary to left heart disease	PH due to HFpEF PH due to HFrEF Valvular disease Congenital disease or cardiovascular condition leading to postcapillary PH	Left heart and/or valve disease signs and symptoms ECHO: right chamber + left chamber and/or valvular changes
III	PH secondary to lung disease and/or hypoxia	COPD Restrictive lung disease Hypoxia without pulmonary disease	Chronic hypoxia at rest and/or on exertion Specific lung function and/or lung imaging test changes Changed polysomnography
IV	PH secondary to pulmonary artery obstruction	Chronic PTE	Dyspnea, edema Ventilation/perfusion scintigraphy and/or chest CT angiography changes Association with neoplasia
V	Multifactorial and/or uncertain mechanisms	Hematologic disease Metabolic and systemic disorder (pulmonary histiocytosis, Gaucher disease, sarcoidosis, neurofibromatosis, glycogen storage disease) Others (chronic kidney disease with or without hemodialysis, fibrosing mediastinitis) Complex congenital heart disease	Signs and symptoms of underlying disease (anemia, metabolic disease)

CCB, calcium channel blockers; COPD, chronic obstructive pulmonary disease; CT, computed tomography; ECHO, echocardiography; HFpEF, heart failure with preserved ejection fraction; HFrEF, heart failure with reduced ejection fraction; HIV, human immunodeficiency virus; mPAP, mean pulmonary artery pressure; PAH, pulmonary arterial hypertension; PAOP, pulmonary artery occluded pressure; PH, pulmonary hypertension; PVR, pulmonary vascular resistance; PTE, pulmonary thromboembolism.

Clinically suspected patients (symptoms and signs on physical examination suggestive of PH) should be referred for echocardiography to assess the echocardiographic probability of PH, right ventricular function, and the presence of severity criteria.^{4,6}

Echocardiographic assessment of PH probability

Echocardiographic PH probability can be classified as low, intermediate, or high. This categorization is based on the assessment of peak tricuspid regurgitation (TR) velocity and the presence of indirect signs suggestive of increased pulmonary vascular bed pressure (Table 2).^{4,6}

Peak TR velocity is the key criterion and should be measured by continuous-wave Doppler during smooth respiration according to the following recommendations:^{4,6-8} (Table 2).

Indirect echocardiographic signs suggestive of PH may be related to the ventricles (group A), pulmonary artery (group B), inferior vena cava, and RA (group C) and should be evaluated according to the following recommendations (Table 3):^{4,6-8}

Assessment of RV systolic function

Due to its anatomical complexity, the RV is the most difficult cardiac chamber to analyze. The architecture of its thin walls (triangular morphology on the long axis, crescent on the short axis) consists of many trabeculations, intertwined longitudinal muscle fibers in the sub-endocardium, and superficial circumferential subepicardial fibers. Its contraction movement resembles a bellows, has a complex mechanism, and occurs predominantly longitudinally from the base to the apex, where the shortening of minor and major axes pulls the tricuspid valve toward the apex. Its thickness does not exceed 5 mm.⁷

Due to this complexity, the functional analysis of the RV has been neglected or evaluated subjectively for years. Studies from the last decade consolidated the importance of the RV in maintaining hemodynamic stability, showing significantly increased morbidity and mortality regardless of the underlying disease in the progression to an advanced stage of RV dysfunction. The clinical need for an accurate RV assessment and the technological advancement of software favored the study of numerous parameters in the search for an earlier diagnosis to delay the disease's natural course.⁹

Cardiac resonance, the gold standard for functional analysis

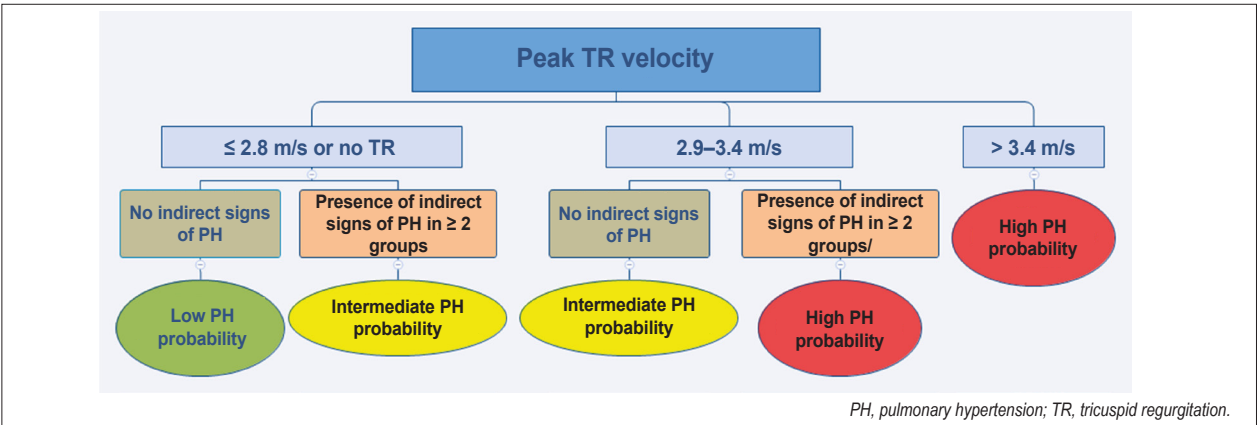


Figure 2 – Estimated echocardiographic PH probability based on peak TR velocity and indirect signs of PH.

Table 2 – Tricuspid regurgitation analysis.

	1. Use several windows (apical four-chamber, short-axis, subcostal, or other modified positions) to obtain the best regurgitant jet envelope. 2. Avoid eccentric jets as they may underestimate measurements. 3. Use high scan velocities (100 mm/s) to better differentiate true velocity from artifacts. 4. Report that the velocities may be underestimated in severe regurgitation, especially when associated with annulus dilation and valve leaflet coaptation failure (there is no gradient between the right atrium and the right ventricle; similar to a single chamber) 5. Average five beats in atrial fibrillation. 6. Right ventricular systolic pressure estimation is not recommended due to the high right atrial pressure variability subjectively caused by inferior vena cava variations.
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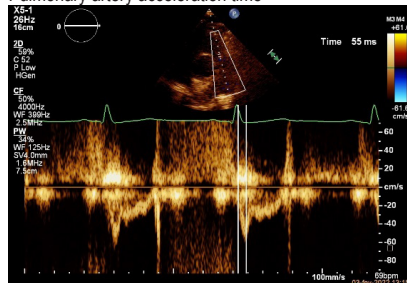
Table 3 – Indirect echocardiographic signs.

Group A – Ventricles	
Ratio of right (RV) and left ventricle (LV) basal diameter measurements	
LV eccentricity Index (LVEI)	Apical four-chamber plane (avoid shortening) Measure LV and RV basal diameters at end-diastole Consider the ratio of basal RV/LV diameter as an indirect criterion for PH, with a value of >1 indicating RV dilation Parasternal short-axis plane – mid-region between papillary muscles and top of mitral valve leaflets End-systole – moment of visualization of the smallest cavity End-diastole – R wave peak Measurement location – D1 is the LV diameter perpendicular to the interventricular septum (IVS), D2 is the LV diameter parallel to the IVS LVEI = D2/D1 Volume overload: changes LVEI only in diastole Pressure overload: changes LVEI in systole and/or diastole Consider as an indirect PH criterion: LVEI > 1.1 in systole or both systole and diastole

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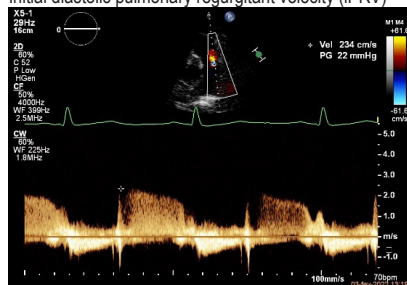
Group B - Pulmonary artery

Pulmonary artery acceleration time



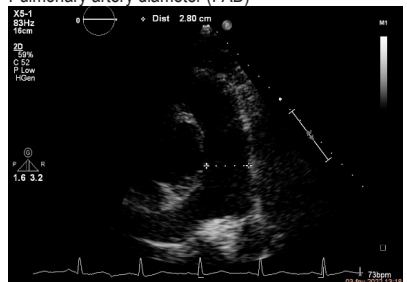
Parasternal short-axis plane
Place pulsed Doppler sample volume in the RV outflow tract (RVOT) - ventricular face (below the pulmonary valve cusps)
Measure time from the beginning to peak pulmonary artery velocity
Measure at the end of expiration
Use a five-beat average in atrial fibrillation
Heart rate (HR) < 70 bpm or > 100 bpm may reduce accuracy – correct with the formula: acceleration time $\times$ 75/HR
HR does not interfere with acceleration time in patients with an invasive mPAP > 25 mmHg
Systolic notching suggests a pattern of high pulmonary circulation resistance
Consider as an indirect PH criterion: AT < 105 ms

Initial diastolic pulmonary regurgitant velocity (iPRV)



Parasternal short-axis or RVOT plane
Align continuous-wave Doppler with the pulmonary reflux jet
Measure initial peak velocity
Consider as an indirect PH criterion: iPRV > 2.2 m/s

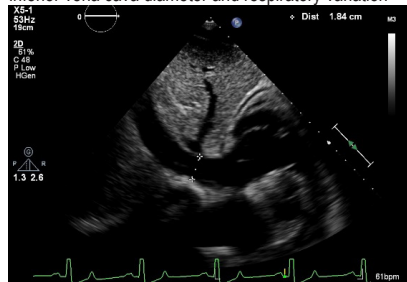
Pulmonary artery diameter (PAD)



Parasternal short-axis plane
Place frame at end-diastole
Measure the lung diameter at the midpoint between the pulmonary valve and the bifurcation point (right and left branch emergence)
Consider as an indirect PH criterion: PAD > 25 mm

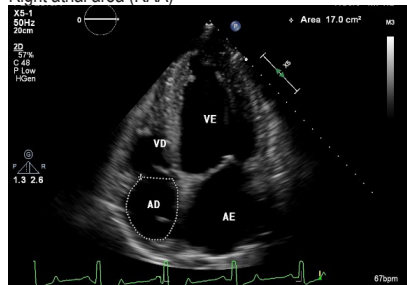
Group C – Inferior vena cava and RA

Inferior vena cava diameter and respiratory variation



Subcostal plane
Measure the diameter 1–2 cm from the junction with the RA
Measure at the end of expiration
Consider as an indirect PH criterion: diameter > 21 mm with reduced respiratory variability (<50% with deep inspiration or <20% with shallow respiration)

Right atrial area (RAA)



Apical four-chamber plane
Measure at the end of ventricular systole (frame before tricuspid valve opening)
Consider as an indirect PH criterion: RAA > 18 cm²

LV: left ventricle; RV: right ventricle; LVEI - LV: eccentricity Index; IVS: interventricular septum; RVOT: right ventricle outflow tract; HR: Heart rate; AT: acceleration time; mPAP: mean pulmonary artery pressure; iPRV: Initial diastolic pulmonary regurgitant velocity; PAD: Pulmonary artery diameter; r - IVC: Inferior vena cava; RA: Right atrial; RAA: Right atrial area.

of the RV, is not influenced by technical image acquisition limitations, but its lower availability, impossible portability, time-consuming performance, and high cost hinder its use as a first-choice method for such purposes. On the other hand, echocardiography, which features low cost and no radiation exposure, has become the most attractive method for the initial assessment of global RV function, being the gold standard method for selected cases.¹⁰

Echocardiography analyzes RV segments by acquiring multiple echocardiographic windows using all the features offered by ultrasound (M-mode, Doppler, 2D, 3D, strain). The first quantitative parameters are derived from basic echocardiography and called classic, conventional, or traditional (Tabela 4). These quantitative parameters aim to detect changes in RV function at an earlier stage but have been criticized for being extremely dependent on pre- and post-load states and inferring that the assessment of a small RV segment may reflect the global function of a highly complex anatomical structure. Despite criticisms and technical difficulties, these parameters are used in clinical practice, being established by both general consensus on chamber quantification and the specific quantification

of the right chambers. Technology has brought advanced parameters derived from myocardial deformation and 3D imaging with the advantages of evaluating more than one RV segment and of not being so influenced by hemodynamic conditions. The low availability of software in devices and the few studies of its standardization among manufacturers are real limitations in daily practice.^{9,11}

The presence of pericardial effusion and measurements of right ventricular diameters and thickness are additional parameters useful in analyzing the severity of pulmonary hypertension and its hemodynamic repercussion on the right chambers (Table 5).

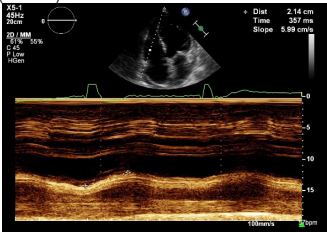
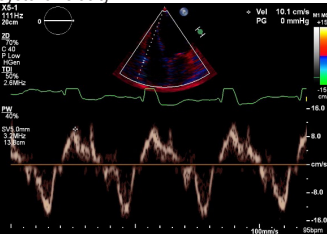
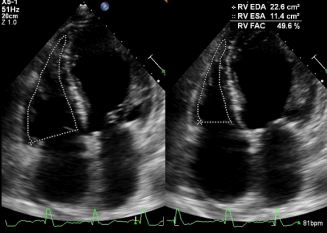
Final considerations

PH is invasively diagnosed only by right heart catheterization (mPAP > 20 mmHg).

Echocardiography is the main test used to screen patients with suspected PH. It aims to estimate echocardiographic PH probability and assess the morph functionality of the right chambers.

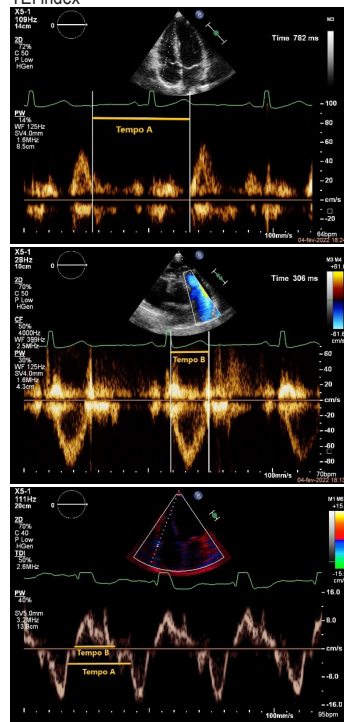
It should not be used to grade PH severity.

Table 4 – Echocardiographic parameters for analysis of right ventricular function.

Classical echocardiographic parameters	
Tricuspid annular plane systolic excursion (TAPSE) 	Technique: - Position the unidimensional mode cursor (M) in the basal region of the lateral tricuspid annulus in the apical four-chamber plane. - Measure from the systolic displacement of the tricuspid annulus Advantages: - Easy to perform - Good correlation with cardiac magnetic resonance imaging data Disadvantages and limitations: - Regional segmental changes - Hemodynamic conditions - Angle of insonation - Cardiac translational movement Consider that the measurement of a basal segment represents the global function of a cavity with complex anatomy. It may be normal in patients with cardiac dysfunction (PH). It may be reduced in patients with preserved right ventricular function (post-cardiac surgery). Consider as dysfunction: TAPSE < 17 mm
S' – TDI – Tissue Doppler tricuspid annular systolic velocity 	Technique: - Position the tissue Doppler sample volume in the basal region of the lateral tricuspid annulus in the apical four-chamber plane - Measure the peak systolic velocity of lateral tricuspid annular motion Advantages: Easy to perform Disadvantages and limitations: - Dependent on insonation angle - Varies greatly with global cardiac motion - Dependent on correct alignment (as parallel as possible) of the Doppler with the tricuspid annular motion Assesses only the basal segment of the RV free wall. Consider as dysfunction: S' - TDI < 9.5 cm/s
MAF/FAC - Fractional area change 	Technique: - Four-chamber apical plane - two-dimensional mode - Trace the endocardial borders of the RV by estimating the area in systole and diastole - Calculate variation using the formula: $MAF/FAC = 100 \times (RV \text{ area in diastole} - RV \text{ area in systole}) / RV \text{ area in diastole}$ Advantage: Enables evaluation of a greater number of RV segments Disadvantages and limitations: - Definition of endocardial borders - Does not consider RV outflow in functional analysis Consider as dysfunction: MAF/FAC < 35%

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MPI/TEI – myocardial performance index or TEI index



Technique:

• Pulsed Doppler:

- In 4C apical plane, position the sample volume atop the tricuspid valve leaflets and measure the time between two tricuspid flows (IVRT + ET + IVCT) – Time A
- In the short-axis plane, position the sample volume in the RVOT (close to the pulmonary valve leaflets) and measure the pulmonary ejection time – Time B

• Tissue Doppler:

- In 4C apical plane, position the sample volume in the basal region of the lateral tricuspid annulus
- Measure the time between two tricuspid flows (IVRT + ET + IVCT) – Time A
- Measure the pulmonary ejection time – Time B

Calculated by dividing the sum of isovolumetric contraction and relaxation times by the RV ejection time (MPI = A - B/B).

Advantage: Tissue Doppler technique acquires A and B times in a single beat of the cardiac cycle

• Disadvantages and limitations:

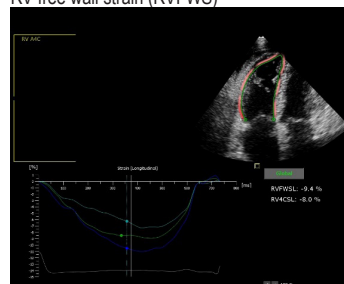
- Pulsed Doppler technique requires beats at different times to acquire A and B times - it can change the results, especially with heart rate variability

It is a global index that assesses RV systolic and diastolic function (not possible to distinguish between them)

Consider as dysfunction: MPI/TEI > 0.43 on pulsed Doppler and > 0.55 on tissue Doppler

Advanced echocardiographic parameters:

RV free wall strain (RVFWS)



Strain is defined as the change in the length (deformation) of the myocardium under the action of a force (fractional change of a myocardial segment in relation to the initial length after the action of a contraction force)

The most common method is speckle tracking using the block matching (region of interest or kernel tracking; Philips and GE) or optical flow techniques (derived from vector velocity; Esaote and Siemens)

It can be evaluated globally by left ventricular global strain or only on the RV free wall (RVFWS) – the latter being more specific by excluding interventricular septum analysis (LV fiber interference)

Technique:

Apical four-chamber plane with optimized image and focused on the RV

Frame rate > 50–60 Hz

Visualize RV apex throughout the cardiac cycle (request apnea if necessary)

Calculate deformation using each manufacturer's own algorithm

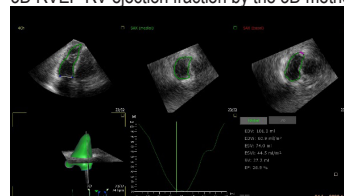
Automatic methods using artificial intelligence have gained more space due to their agility and good correlation with the gold standard method.

Advantages: Reproducible and independent of the angle of insonation and translational movement

Disadvantages: Does not consider RVOT, variability between manufacturers, image quality

Consider as dysfunction: RVFWS < -20% correlates with a reduced RV ejection fraction

3D RVEF-RV ejection fraction by the 3D method



Apical four-chamber plane focused on the RV

Use a 3D transducer and acquire the RV full volume encompassing the tricuspid and pulmonary valves

Acquire it at the highest possible frame rate – preferably > 20 Hz

Reconstruct with specific software (according to the manufacturer) to calculate volumes and ejection fraction

Advantages:

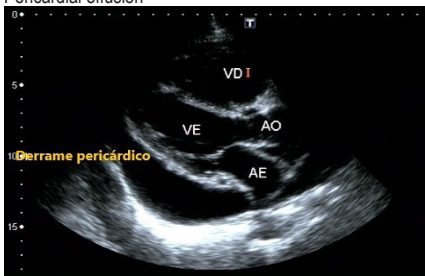
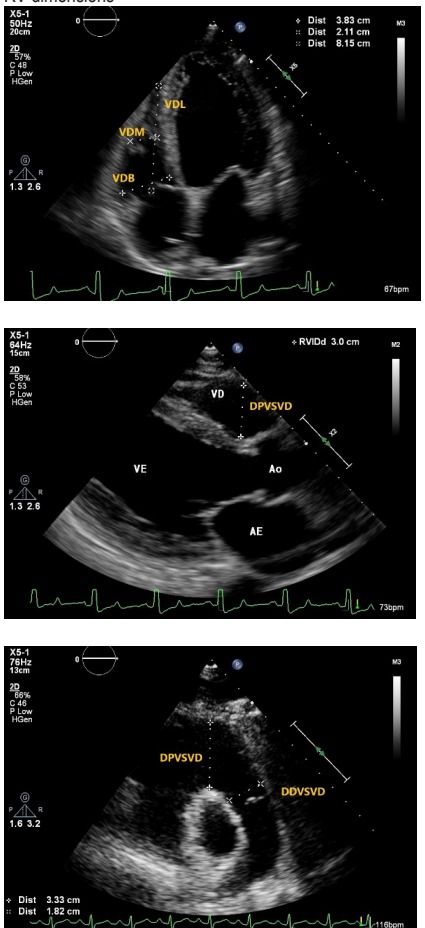
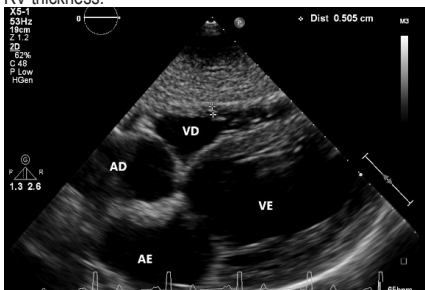
- Enables better anatomical assessment (includes all RV segments)
- Assesses RV longitudinal and radial contraction
- Assesses anteroposterior shortening

Limitations:

- Dependent on pre- and post-load states
- Image must be of good quality to enable endocardial border identification
- Artifacts produced by arrhythmias
- Acquisition and processing time
- Availability (of the 3D transducer and quantification software)
- Consider as dysfunction: 3D RVEF < 45%

TAPSE = Tricuspid annular plane systolic excursion; TDI - Tissue Doppler; RV = Right ventricle; FAC = Fractional area change; RIMP or Tei index = Right ventricular index of myocardial performance; IVRT = Isovolumic relaxation time; ET = Ejection time; IVCT = Isovolumic contraction time; RVFWS – RV free wall strain; RVGS – RV global strain; 3D RVEF - 3D Right ventricle Ejection fraction; RVOT = Right ventricular outflow tract.

Table 5 – Additional echocardiographic parameters for RV assessment.

Pericardial effusion 	Related to the natural disease course and its prognosis Absence of stroke indicates better prognosis Presence of stroke associated with advanced disease and worse prognosis
RV dimensions 	PH increases pre- and post-load with progressive RV dilation RV inflow tract plane: Modified apical four-chamber window for RV Visualize RV apex Avoid RV shortening (can be technically difficult due to crescent shape) Measure the RV at end-diastole Basal diameter of the RV (BRV) - Maximum transverse diameter at the base of the RV - Consider as increased: BRV > 41 mm Mean RV diameter (MRV) - Transverse diameter measured at LV papillary muscle level - Consider increased: MRV > 35 mm Longitudinal RV diameter (LRV) - Longitudinal length from the tricuspid annular plane to the RV apex - Consider increased: LRV > 83 mm RVOT plane: RVOT proximal diameter (RVOTPD): -- Linear measurement taken at end-diastole from the RV anterior wall to the septum-aortic interventricular junction in long-axis parasternal window. Consider as increased: RVOTPD long axis > 30 mm -- Linear measurement taken at end-diastole from the anterior wall of the RV to the aortic valve in sternal short-axis window. Consider increased: RVOTPD short axis > 35 mm RVOT distal diameter (RVOTDD): Linear measurement taken at the close proximal end pulmonary valve diastole in sternal short-axis window. Consider increased: RVOTDD > 27 mm
RV thickness: 	PH causes RV hypertrophy Method: Subcostal or apical four-chamber plane Measure RV thickness using 2D or M-mode at end-diastole Measurement location: RV free wall below the tricuspid annulus (distance from valve plane equivalent to the point at the top of the fully open anterior leaflet and parallel to the free wall) Limitations: Single point measurement Harmonic imaging and angled M-mode may overestimate thickness Technical difficulty in cases of pericardial thickening Consider hypertrophy: thickness > 5 mm

PH: Pulmonary hypertension; RV: right ventricle; BRV: basal diameter of the RV; MRV: mean RV diameter; LV: left ventricle; LRV: longitudinal RV diameter; RVOTPD: right ventricle outflow tract proximal diameter; RVOTDD: right ventricle outflow tract distal diameter.

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Authors' contributions

manuscript writing: Masson Silva JB; critical review of the manuscript for important intellectual content: Júnior CGS

Conflict of interest

The authors have declared that they have no conflict of interest.

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