Echocardiographic Evaluation of Pulmonary Hypertension in Children

Avaliação Ecocardiográfica da Hipertensão Pulmonar em Crianças

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Abstract

Hypertensive Pulmonary Disease (HPD) can be defined as a set of pathophysiological pulmonary disorders that result in severe, progressive disease with high morbidity and mortality. Transthoracic echocardiogram (TTE) is an easily accessible and essential imaging method for the evaluation of this disease, especially in children, where there are limitations to frequent and routine right-heart catheterization. In this review, we address the main echocardiographic techniques for the diagnosis and hemodynamic evaluation of pulmonary hypertension in the pediatric population. Early diagnosis and appropriate staging in the follow-up of clinical interventions are fundamental for the assertive choice of therapeutic approach and, consequently, improvement of clinical outcomes.

Introduction

HPD is a set of pathophysiological pulmonary disorders that result in severe, progressive pathology with high morbidity and mortality in both adults and in children. The natural course of this syndrome involves the progressive increase of pulmonary vascular pressure and resistance, culminating in right ventricular failure, clinical deterioration and death.[1,2] Pulmonary hypertension (PH) is diagnosed when the mean pulmonary pressure is greater than 25 mmHg at rest with pulmonary wedge pressure smaller than or equal to 15 mmHg and an increase in pulmonary vascular resistance greater than 3 UW (Table 1) in adults or pulmonary vascular resistance index greater than 2UW/m^2.[1,3]

However, each case should be evaluated individually, especially in the pediatric population, for example: In patients with univentricular congenital heart disease following Glenn/Fontan surgery, venous return is passive to the pulmonary arteries, so even a slight increase in PVR may result in low cardiac output, even if the mean pulmonary artery pressure is below 25 mmHg.[4,5]

The gold standard imaging method is cardiac catheterization, which is able to accurately measure pulmonary pressure and resistance. However, its performance is more complex in the pediatric population due to the need for general anesthesia, contrast and radiation, presenting higher risks for the patients. Thus, echocardiography (TTE) is a very useful noninvasive tool in this group.[6] In addition to its noninvasibility and lower patient risk, TTE enables rapid bedside assessment of cardiac anatomy, right ventricular function, pulmonary pressures, and hemodynamic response to clinical interventions.[7,8]

Keywords

Hypertension, Pulmonary; Pediatrics; Echocardiography.

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Table 1 - Definition of pulmonary hypertension with parameters evaluated by catheterization.

Pulmonary arterial hypertension. Definition
PmPA>25 mmHg
PWP<15 mmHg
PVRI>2 UW/m^2

PmPA: Mean pulmonary artery pressure. PWP: Pulmonary wedge pressure. PVRI: pulmonary vascular resistance index.

Classification

In 1998, during the second world symposium on pulmonary hypertension (PH) in Evian, France, pulmonary hypertension (PH) was classified into 5 categories based on clinical parameters ("Evian Classification").[9,10] Since then, a number of modifications have been implemented based on progress made on understanding the disease in world meetings when, in 2013, during the 5th HP World Symposium held in Nice, France, classification and definition were described as they are currently used.[11] (Table 2)

Classification in PH is based on sets of different clinical conditions, categorized into 5 major groups. Group 1: Pulmonary hypertension (e.g.: idiopathic, secondary to systemic diseases, schistosomiasis), group 2: Pulmonary hypertension secondary to left heart disease (e.g.: Left ventricular systolic or diastolic dysfunction, heart valve disease, congenital pulmonary vein stenosis), group 3: Pulmonary hypertension secondary to pulmonary disease and/or hypoxia (e.g.: Interstitial lung disease, chronic obstructive pulmonary disease), group 4: Chronic pulmonary thromboembolism (PTE) or other arterial obstructions (e.g.: Chronic PTE, arteritis), group 5: Multifactorial pulmonary hypertension (e.g.: chronic hemolytic anemia, splenectomy)[3,6,12,13] as shown in Table 2.

PH stratification

PH can be stratified for better clinical management[14] according to Table 3.

Table 2 - Classification of pulmonary hypertension.

Pulmonary hypertension
Idiopathic
Hereditary
Drug and toxin induced
Associated with:
- Connective tissue disease
- HIV infection
- Portal hypertension
- Congenital heart disease
- Schistosomiasis
- Pulmonary hemangiomatosis or pulmonary veno-occlusive disease
- Fetal pattern persistence
Pulmonary hypertension secondary to left heart disease
Left ventricular systolic diameter
Left ventricular diastolic diameter
Valvular heart disease
Congenital or acquired LV outflow tract obstruction and congenital cardiomyopathies
Pulmonary hypertension secondary to pulmonary disease and/or hypoxia
Chronic obstructive pulmonary disease
Interstitial lung disease
Other pulmonary diseases with mixed restrictive/obstructive pattern
Sleep-associated respiratory diseases
Alveolar hypoventilation
Chronic exposure to high altitudes
Pulmonary development abnormalities
Chronic thromboembolic pulmonary hypertension
Pulmonary hypertension with multifactorial mechanisms
Hematological disorders: chronic hemolytic anemia, myeloproliferative diseases, splenectomy
Systemic diseases: Sarcoidosis, pulmonary histiocytosis, lymphangioleiomyomatosis
Metabolic diseases: Gaucher's disease, thyroid disease
Other: Tumor obstruction, fibrosing mediastinitis, chronic renal failure, segmental PH

HIV: Human immunodeficiency virus. LV: Left ventricle. PH: Pulmonary hypertension. Adapted from Simmonneau et al., 2013[11]

Table 3 - Echocardiographic classification of pulmonary hypertension in children.

Classification	Severity classification of PH in children
Mild	RVSP 1/3 to ½ systemic pressure, RV dilation or mild hypertrophy, septum rectification at systole, normal RV function
Moderate	RVSP ½ to 2/3 of systemic pressure, RV moderate dilation or RV hypertrophy, septum rectification, RV dysfunction may occur
Severe	RVSP>2/3 systemic, predominantly R-L flow if shunt occurs, septum rectification throughout the cardiac cycle and LV compression, RV dysfunction, major RV dilation and hypertrophy

RVSP: Right ventricular systolic pressure.

Echocardiographic evaluation in pulmonary hypertension

TTE should always be performed when pulmonary hypertension is suspected. It is the noninvasive test of choice for investigation in patients with suspected PH (Class I, level C).[3, 8] This review will consider the main echocardiographic parameters for evaluation of children with PH.

Anatomic evaluation

Inferior vena cava

Evaluation of inferior vena cava (IVC) is performed through the long axis subcostal view (Figure 1). The IVC pathway to the right atrium inflow tract, dimensions and collapsibility throughout the respiratory cycle should be observed. An indirect estimate of right atrial pressure (RAP) is then made. In the adult population, in the IVC diameter ≤2.1cm that collapses ≥50%, a RAP variation of 0–5 mmHg can be estimated. In the IVC>2.1 cm that collapses <50%, it can be inferred that there is an increase in filling pressures with a RAP variation of 10–20 mmHg. The collapsibility index should be calculated using the equation Dmax-Dmin/Dmax, where Dmax is the maximum IVC diameter and Dmin is the minimum diameter measured as in Figure 1. This measurement is expressed as a percentage.[15] In children, indirect assessment of IVC dimensions can be performed and collapsibility should be considered primarily.

Patients with PH often present dilation and reduction of IVC collapsibility, losing their value in estimating blood volume using IVC collapse or distensibility index.[16]

Right atrium

Increased right ventricular (RV) filling pressures secondary to reduced ventricular compliance of patients with PH lead to right atrial dilatation over time. Evaluation of right atrial (RA) dimensions can be performed by the apical four-chamber view in which the major and minor axes should be measured and atrial planimetry should be performed (Figure 2). The reference value for RA area in adults is considered to be less than 18 cm^2, for the diameter of the major axis it is smaller than 5.3 cm and for the minor axis it is smaller than 4.4 cm.[16,17] In children, planimetry indexed by body surface may be performed.[18]

Right ventricle

Chronic pressure overload in patients with PH leads to right ventricular hypertrophy and dilation and consequent loss of systolic function, which is directly related to the patients' quality of life and survival. RV anterior wall thickness evaluation (RVAWT) is a useful tool. RVAWT should be evaluated by subcostal view and has a reference value smaller than 5 mm.[16,17] (Figure 3)

Access to right ventricular (RV) morphology is known to be complex through two-dimensional echocardiography, so it should be visible in several views for its full evaluation.[6,16] It is essential to evaluate RV in subcostal view, in which 4-chamber axis and short axis must be evaluated; parasternal

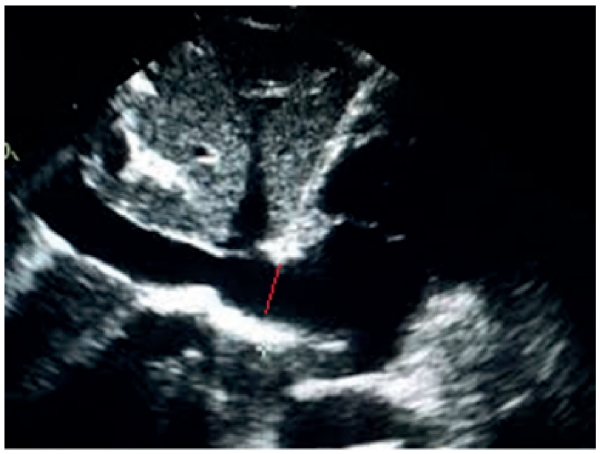


Figure 1 – *Subcostal plane showing inferior vena cava into the right atrium. The red line shows where its dimensions should be measured.*

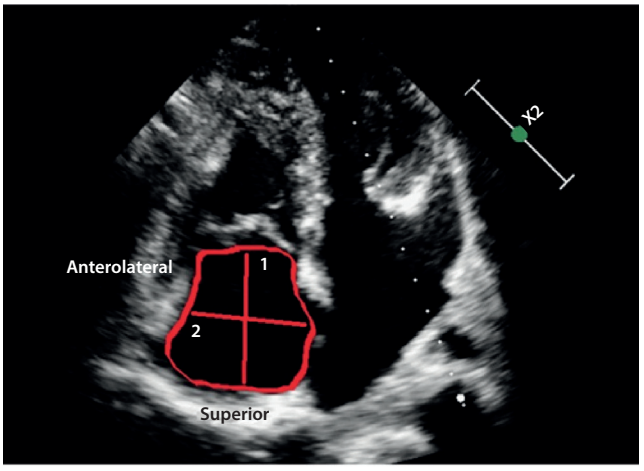


Figure 2 – *Apical four-chamber view. The RA route is performed from the tricuspid valve annulus plane along the interatrial septum. The major axis is represented by line 1 and the minor axis by line 2.*

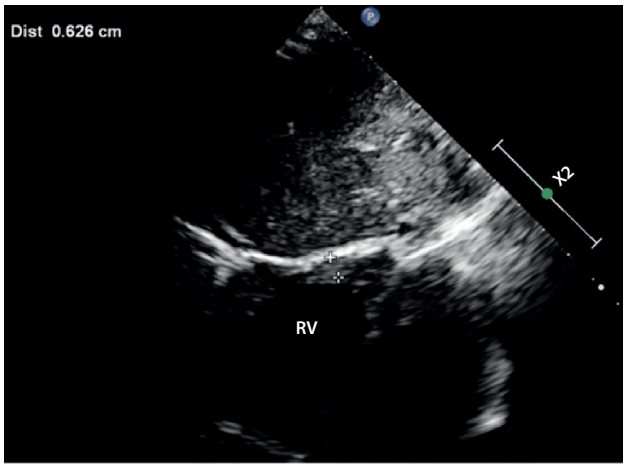


Figure 3 – *Subcostal plane shows the measurement of right ventricular anterior wall thickness.*

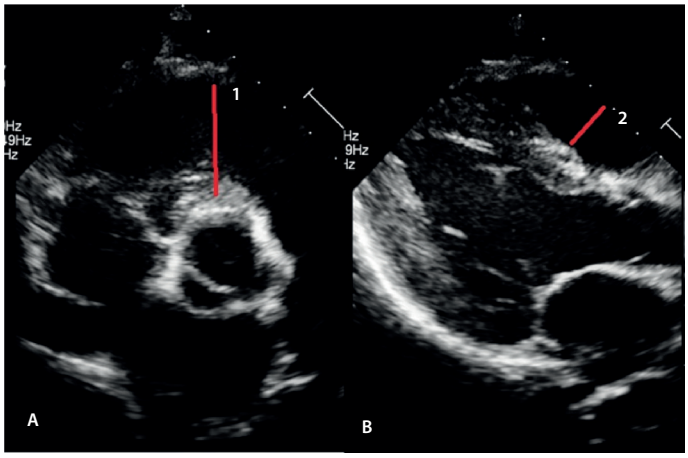


Figure 4 – *It shows the parasternal plane during telediastole, lines 1 and 2 show where the RV outflow tract measurements should be performed. (A) Parasternal short axis view. (B) Parasternal long axis view including the anterior portion of the RV outflow tract.*

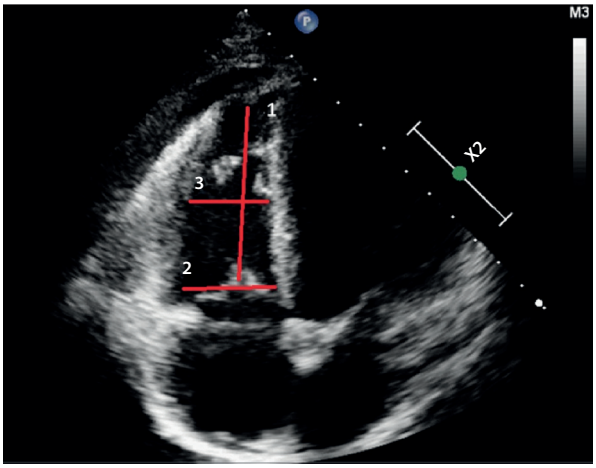


Figure 5 – *Image obtained through apical four-chamber view showing (1) longitudinal axis, (2) basal diameter and (3) medium diameter.*

view, in which long and short axes must be evaluated during telediastole and RV outflow tract must be evaluated (Figure 4); and apical 4-chamber view, in which the longitudinal, basal (near the tricuspid valve annulus) and medium diameter must be measured, as shown in Figure 5.

RV/LV ratio

Interventricular septum (IVS) provides valuable information on patients with suspected PH, as RV pressure overload leads to IVS rectification at the end of systole resulting in a "D"-shaped left ventricle when viewed on parasternal short axis view. If it is not possible to estimate pulmonary pressure, IVS evaluation offers indirect evidence of increased right chamber pressures.[16]

Evaluation of RV diameter to LV diameter ratio (RV/LV ratio) at the end of systole has been cited as a marker of increased pulmonary pressure in adults and children and correlated with catheterization measurements. The RV/LV ratio must be measured between end-systolic papillary muscles on parasternal short axis view (Figure 6). RV/LV ratio > 1 is associated with worse clinical outcome in children with PH.[17,19,20]

Eccentricity index

The pressure increase in the right chambers leads to systolic rectification of the interventricular septum. The eccentricity index (EI) derives from the ratio between the left ventricular anteroposterior and septolateral diameters on parasternal short axis view at the papillary muscle level at the end of ventricular systole (Figure 7). Abraham et al.[21] evaluated 216 newborn echocardiograms and found a positive correlation between EI and pulmonary pressure, suggesting that it is a routine method used for neonatal evaluation. EI>1.3 is related to pulmonary pressure greater than half the systemic pressure with good specificity.

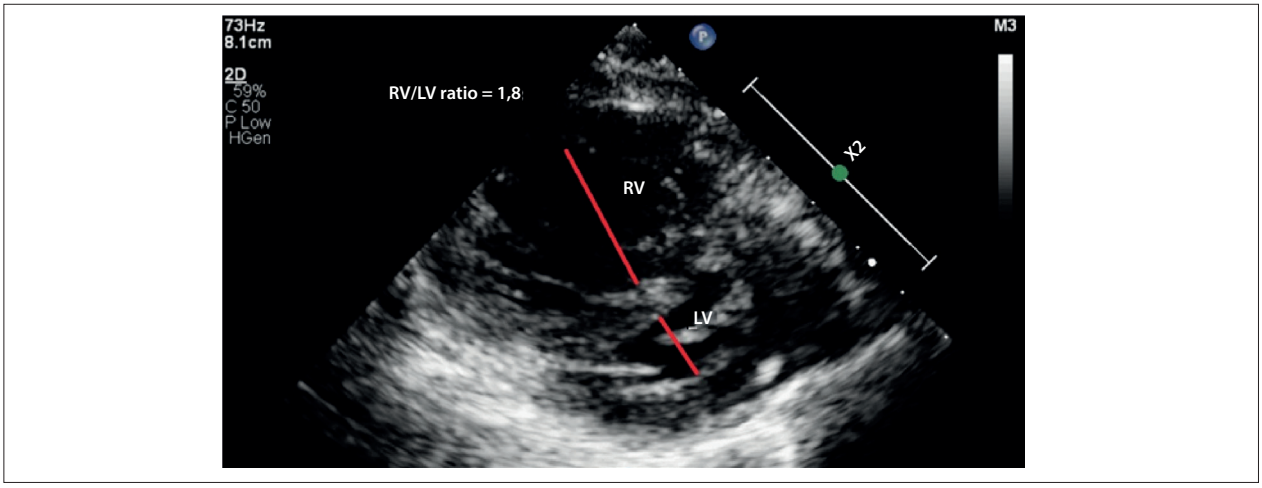


Figure 6 – *RV/LV ratio. The figure shows end-systolic parasternal short axis view of the ventricles. The arrows show measurements of left ventricular papillary muscles.*

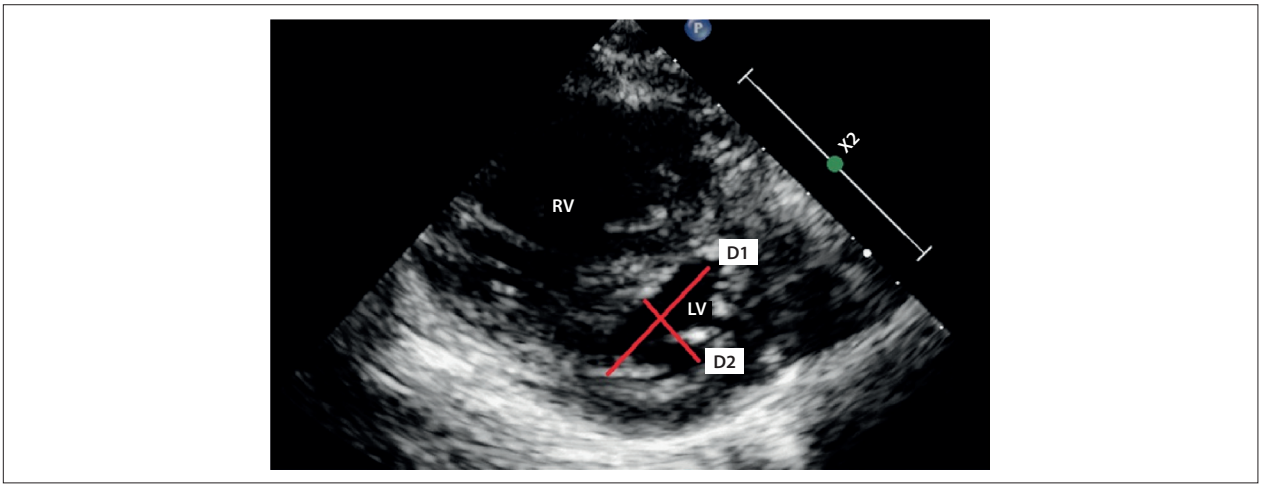


Figure 7 – *End-systolic parasternal short axis view. The eccentricity index is the D1/D2 ratio.*

Intracardiac shunt

In situations of normal pulmonary pressure, intracardiac shunts, such as atrial and ventricular septal defects (ASD/VSD), and through the persistent ductus arteriosus (PDA), present directed flow from the left to the right chambers (red flow on color flow mapping). Pulmonary pressure can be estimated in the presence of VSD and PDA by continuous flow Doppler in these defects. Maximum gradient must be obtained and systemic systolic pressure subtracted. When there is significant PH, pressure in the right chambers may be higher than in the left chambers, causing flow reversal from the right to the left cardiac chambers. This is called the Eisenmenger Syndrome.

Heart valves

Evaluation of heart valves in patients with suspected PH should focus on ruling out the possibility of increased right ventricular pressure secondary to RV outflow tract obstruction (pulmonary stenosis) or increased pulmonary pressure secondary to anatomical valvular disorder, such as mitral stenosis/regurgitation and pulmonary vein stenosis (post wedge PH).[6]

Pericardial effusion

The presence of pericardial effusion has been associated with worse clinical outcome in adults, but there was no correlation with outcome in children.[22]

Functional evaluation

Pulmonary artery systolic pressure

Pulmonary artery systolic pressure (PASP) can be estimated by assessing the maximum velocity of the tricuspid valve regurgitation jet (V_{tric}) using the following equation PASP = 4 x V_{tric}^{2} + DBP (which vary according to the inferior vena cava collapsibility as previously described).[16,23]

The Doppler curve is to be acquired with good quality, forming an envelope, otherwise pulmonary pressure may be underestimated. If it is not possible to acquire an adequate curve and there are no intracardiac defects, pulmonary systolic pressure cannot be estimated. The reference values defined for assessing patients at rest is V_{tric} smaller than or equal to 2.8 m/s or PASP smaller than or equal to 35 mmHg,[1,16] according to Figure 8.

PASP can also be obtained if the patient has restrictive ventricular septal defect (VSD) by simply having access to systemic systolic pressure (SBP) using the following equation: PASP = SBP - 4x Vmax (VSD)^2, where Vmax (VSD) is the maximum velocity of flow through VSD. In the case of low velocity flow or bidirectional flow, major PH is suggested.

Mean diastolic pulmonary artery pressure

In the presence of pulmonary insufficiency (PI), it is possible to estimate mean diastolic pulmonary artery pressure.

Early LD jet velocity and end LD jet velocity must be recorded on Doppler (Figure 9).

Mean pulmonary artery pressure (MPAP) value is calculated with the following formula: MPAP (mmHg) = 4 x (early LD velocity) 2+ DBP. The normal value of mean pulmonary artery pressure is ≤ 25 mmHg.[16,24] Diastolic pulmonary artery pressure (DPAP) is calculated using the formula below: DPAP (mmHg) = 4 x (end PI velocity) 2 + DBP. Normal pulmonary artery diastolic pressure is ≤ 14 mmHg

Pulmonary artery flow acceleration time

Pulmonary artery flow acceleration time (ACT) determined by pulsed pulmonary artery Doppler has recently been described as a potential tool for the evaluation of children with PH. In a recently published study, in which 756 healthy children aged 0 to 18 years were studied, pulmonary ACT correlated positively with weight, age, body surface area and negatively with heart rate.[25] Increased PVR and pulmonary pressure added to the loss of compliance leads to reduced flow velocity resulting in a more triangular Doppler curve. In some cases, there may be a notch in the pulmonary artery Doppler.

Pulmonary ACT must be calculated using pulmonary artery Doppler (Figure 10) and indexed by body surface area and gender. ACT shortening (Z score <-2) is predictive of PH.[25]

Right ventricular function

Assessment of RV systolic and diastolic functions strongly correlates with prognosis in patients with PH.[26,27] There are several methods for assessing RV systolic function; we will describe those with the greatest impact on clinical outcome.

Tricuspid annular plane systolic excursion (TAPSE)

The systolic movement of the RV free wall is a marker of displacement of RV longitudinal fibers. TAPSE is a method for measuring the distance of tricuspid annular plane systolic excursion toward the cardiac apex. It is acquired in apical 4-chamber view, usually by positioning the Mode M cursor on the lateral portion of the tricuspid valve annulus (Figure 11).

The greater the range of motion, the better the systolic function. TAPSE measurement negatively correlates with pulmonary vascular resistance and pulmonary pressure values.[17,28–30] The reference value is greater than 16 mm in adults.[16] In children, there are publications with well-established Z scores.[31]

Right ventricular fractional area change (FAC)

FAC is a measure of systolic function that evaluates RV overall systolic function and can be obtained with the two-dimensional image of RV-modified 4-chamber apical view in which the endocardial walls in diastole (end-diastolic area) and systole (end-systolic area) should be traced, as shown in

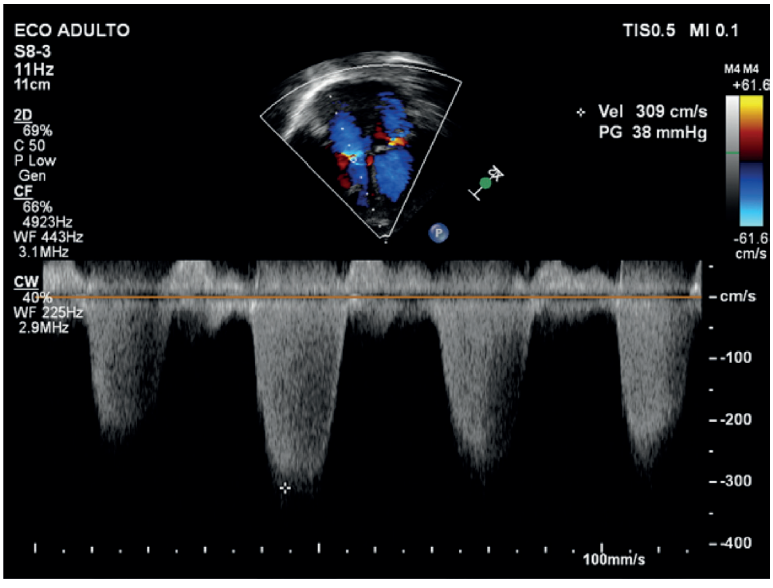


Figure 8 – *Tricuspid valve Doppler showing regurgitation jet and estimation of pulmonary systolic pressure in patients with pulmonary hypertension.*

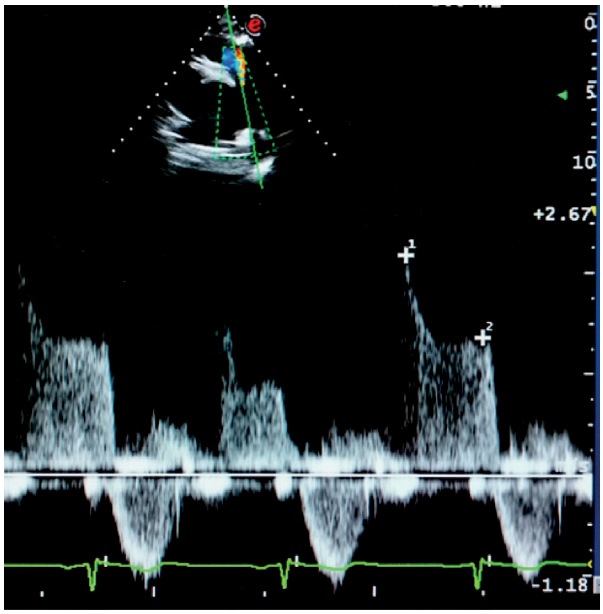


Figure 9 – *Pulmonary Doppler showing early and end velocities of pulmonary insufficiency (PI) jet.*

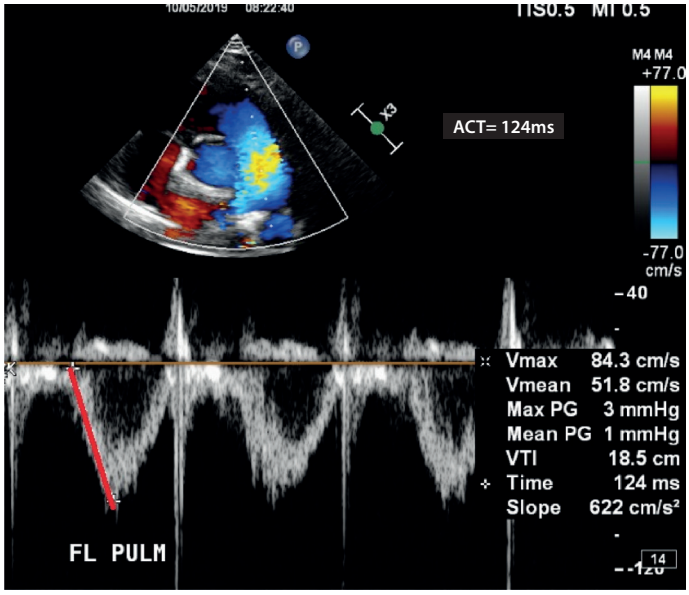


Figure 10 – *Pulmonary artery Doppler: the red line shows the cursor location for the calculation of ACT.*

Figure 12. FAC can be obtained with the following equation:

$$FAC = \frac{\text{end-diastolic area - end-systolic area}}{\text{End diastolic area}} \times 100$$

The FAC reference value is above 35%.[16]

RV tissue Doppler

From the evaluation of myocardial velocities throughout the cardiac cycle by tissue Doppler, the myocardial performance index (MPI) can be calculated and the tricuspid lateral annular S-wave velocity can be determined.

RV MPI is an evaluation parameter for the RV overall

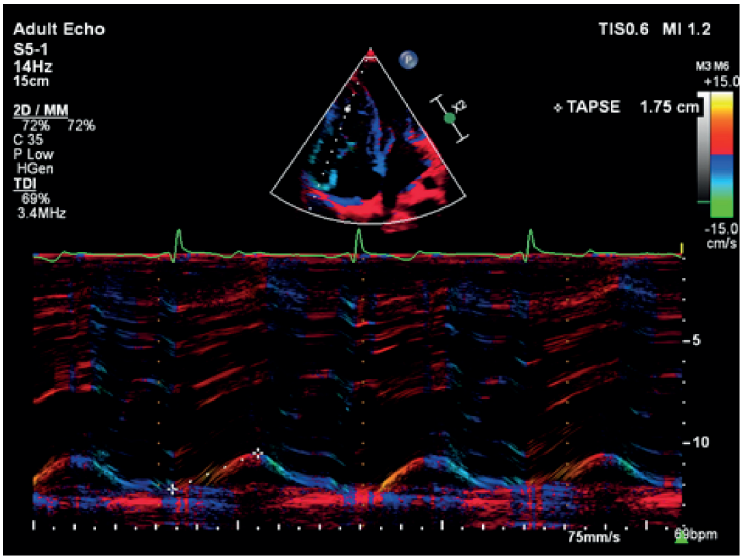


Figure 11 – *Image shows Color M Mode with cursor positioned on the tricuspid valve annulus to obtain TAPSE.*

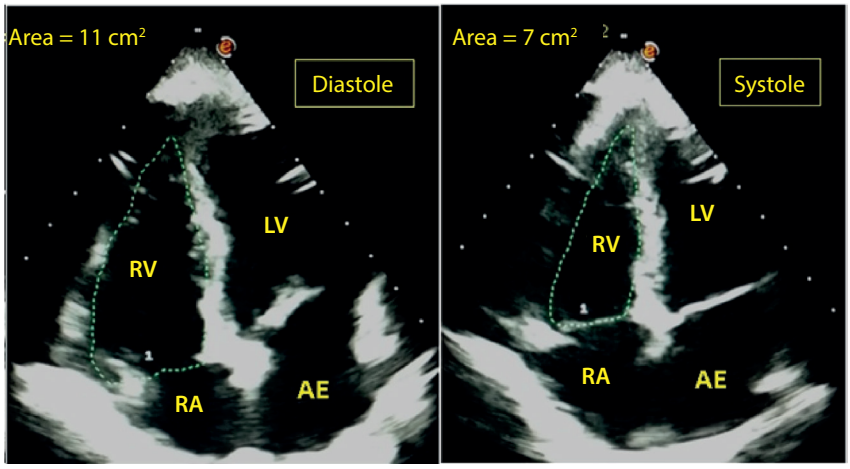


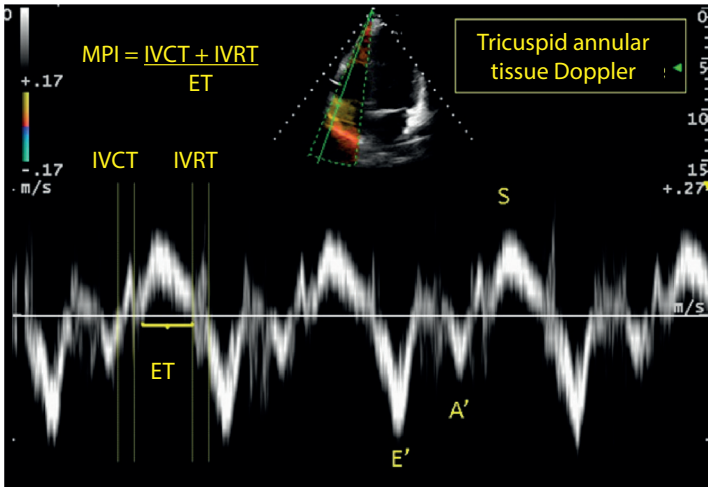
Figure 12 – *Apical 4-chamber view showing the fractional variation of the RV area. FAC: (11-7)/11 = 36%.*

systolic and diastolic performance. It can be calculated by tissue Doppler, on 4-chamber apical view, with cursor positioned on the RV free wall (Figure 13):

$$MPI = \frac{\text{(isovolumetric relaxation time} + \underline{\text{isovolumetric contraction time)}}}{\text{Ejection time}}$$

In cases of systolic dysfunction, RV ejection time decreases, reducing the denominator and increasing the final MPI. Abnormal ventricular relaxation (diastolic dysfunction) leads to prolonged isovolumetric relaxation time, increasing the numerator and also increasing the final MPI. High MPI is indicative of systolic and/or diastolic dysfunction. The reference values for RV MPI also vary according to age, so Z score calculation is advisable.[32,33] The MPI reference value by RV tissue Doppler in adults is smaller than 0.55.[16]

S-wave velocity: RV systolic function can be inferred by measuring the free wall S-wave velocity (Figure 14). S-wave velocity <9.5 cm/s indicates right ventricular systolic dysfunction in adults.[16,24] In children, Eidem[33] found a positive correlation between increased S-wave velocity and the patient's age. Z score <-2 is considered abnormal.



IVCT: isovolumetric contraction time; IVRT: isovolumetric relaxation time; ET: ejection time.

Figura 13 – *RV myocardial performance index (MPI) obtained by tissue Doppler.*

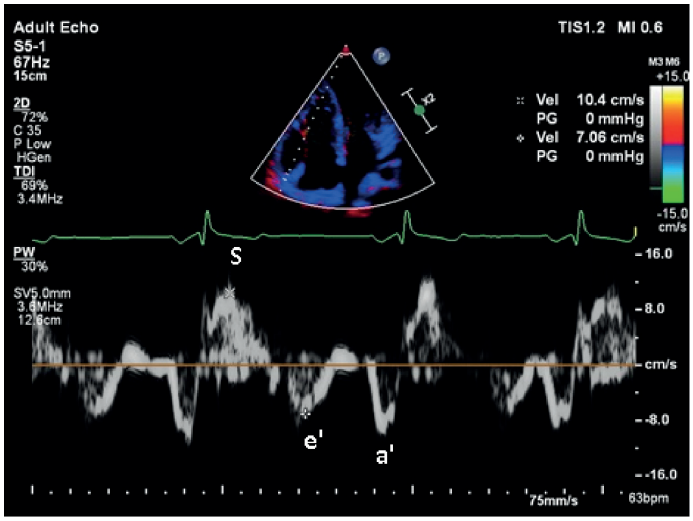


Figure 14 – *Tissue Doppler of right ventricular free wall with e' and S-wave velocities.*

Right ventricular longitudinal peak systolic strain

Access to RV systolic function can be achieved by several conventional parameters, which are influenced by the insonance angle and the complex geometry of this chamber. Strain assessed by the speckle tracking measures the percentage of myocardial strain and makes a global and regional assessment of ventricular systolic function.[34,35] (Figure 15)

Recent publications have shown that two-dimensional RV Strain can be a more sensitive tool than other parameters for early detection of subclinical RV dysfunction, thus predicting clinical outcome and correlating with laboratory and functional class markers after clinical treatment of PH.[16,34,36,37] Okumura[34] evaluated RV strain of children with PH and found that the risk for transplantation was significantly increased when strain was greater than -14%.

Right atrial strain

Increased right atrial pressure is a risk factor for increased mortality in patients with pulmonary hypertension. Strain evaluated by the speckle tracking can also be used to access atrial function, which can be divided into 3 phases: Reservoir phase (during atrial filling), conduit phase (during passive emptying) and pump phase (during atrial contraction). Recently published studies with children suggest that reserve and conduit function values are significantly small in children with pulmonary hypertension (Figure 16).[38]

RV diastolic function

RV diastolic function should be accessed when right atrial pressure elevation is suspected and when there are signs of

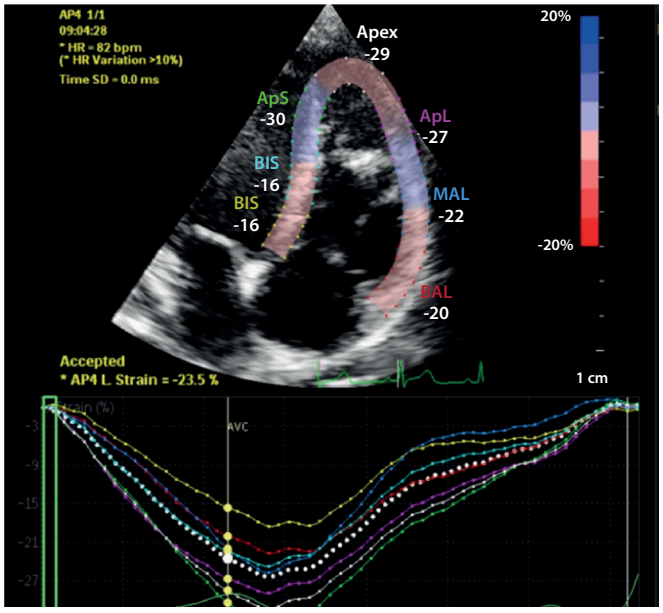


Figure 15 – *Peak systolic right ventricular global longitudinal strain. On the image at the top, two-dimensional global right ventricular strain from the patient with pulmonary hypertension. On the image at the bottom, curves with segmental analysis of myocardial segments and reduced longitudinal right ventricular strain (GS: 23.5%).*

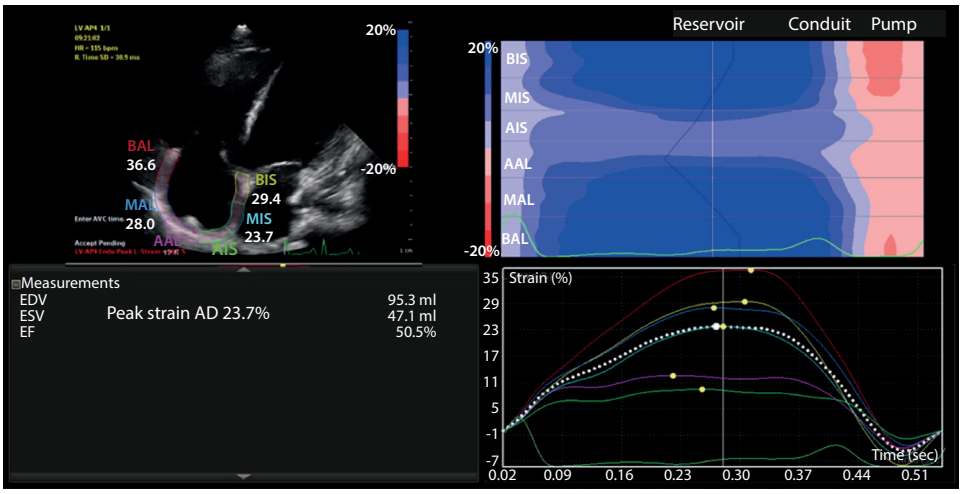


Figure 16 – *Right atrial strain in the upper left frame. The upper right frame shows atrial reservoir, conduit and pump function in M-mode color map. Bottom right frame shows volume x time graph with the curves of each atrial segment in the three phases.*

ventricular systolic dysfunction. Apical 4-chamber view should derive pulsed Doppler of the tricuspid valve and tissue Doppler of RV free wall. E/A ratio <0.8 suggests abnormal relaxation. E/A ratio of 0.8–2.1 and E/e' ratio >6 with predominant diastolic flow in the hepatic veins suggest pseudonormal filling. E/A ratio >2.1 with deceleration time <120ms suggests restrictive filling in adults.[16] In children, Cantinotti[39] published a meta-analysis that reviewed 33 articles in an attempt to establish a normogram for assessment of diastolic function in the pediatric population, finding a negative correlation of E/e' ratio with age. Eidem[33] evaluated 325 children aged 1 to 18 and found a standardized Z-score model of Doppler velocities (Figure 14) indexed by body surface.

Left ventricular systolic and diastolic function

Left ventricle (LV) is usually of normal size in mild PH. During its course and as the right ventricle expands, interventricular septum bulges to the left ventricle (Figure 3), which can be seen in both parasternal long axis and short axis; in extreme cases, the septum is so bulged to the left ventricular outflow tract that it may restrict ventricular filling.[17]

Echocardiographic evaluation of patients with PH must include left ventricular (LV) systolic and diastolic evaluation, analyzing the possibility of PH secondary to left heart disease. Systolic function may be abnormal due to many different factors, including pulmonary hypertension, low cardiac output and chronic inflammation.[26] Systolic function can be assessed by biplane Simpson's method. Diastolic function should be assessed by mitral valve pulsed Doppler and LV septal and lateral wall tissue Doppler. RVs are E/A of 0.8–2.0 and E/e' <8 in adults.[1,26,40] In children, velocity values can be indexed by body surface and the Z score evaluated.[32]

The echocardiographic parameters and reference values recommended for evaluation of pulmonary hypertension are summarized in Table 4.

Conclusion

PH is a serious progressive disease with high morbidity and mortality secondary to right ventricular failure. Echocardiography is a fundamental noninvasive tool for the diagnosis and follow-up of PH, especially in the pediatric population, in which catheterization, which is an extremely important test for initial diagnosis of the disease, has a higher number of complications compared to the adult population. TTE allows bedside assessment of cardiac anatomy, ventricular function and hemodynamic assessment before and after clinical interventions.

In this article, we made an updated review of the main echocardiographic parameters for the evaluation of PH that showed relevant prognostic value in children. We concluded that more than purely measuring variables, it is important for the echocardiographer to understand PH and perform an analysis focused on the diagnosis and staging of the disease, which requires familiarity with traditional techniques and new evaluation techniques. Routine use of these techniques and protocols will lead to early diagnosis and treatment, directly impacting the patient's clinical outcome.

Table 4 - Echocardiographic parameters recommended for evaluation of PH in children.

Echocardiographic measurement	Reference value	Comments
PASP estimate	VRVT≤2,8 mm/s or PASP≤35 mmHg, VRVT>3,4 m/s=high risk for HP	VT regurgitation jet. Obtain good envelope (up to 25% no good curve is obtained). Figure 8
MPAP and DPAP estimate	MPAP≤25 mmHg/DPAP≤14 mmHg	Max and min velocities on PI. Add RA pressure. Figure 9
Dimensions of right chambers	http://www.parameterz.com/refs/cantinotti-jase-2014-december http://www.parameterz.com/refs/rajagopal-pedcard-2018 http://www.parameterz.com/refs/koestenberger-ajc-2014	Quantity. RA area. RV diameters, body surface index. Figures 4 and 5
TAPSE	http://parameterz.blogspot.com/2010/12/tapse-rv-function-z-scores.html	Good correlation with ejection fraction and mortality. Figure 11
FAC	VN≥35%	Requires good wall view. Figure 12
RV/LV ratio	RV/LV ratio>1 associated with worse prognosis	Parasternal position, short axis, end of ventricular systole. Figure 7.
Eccentricity index	IE<1,3	Parasternal position, short axis, end of ventricular systole. Figure 7.
RV MPI	0,55 (adults). Z score for children http://www.parameterz.com/refs/eidem-jase-2004	RV free wall tissue Doppler. Figure 13
S wave velocity	>9,5 cm/s (adults). Z score <-2 = ventricular dysfunction http://www.parameterz.com/refs/eidem-jase-2004	RV free wall tissue Doppler. Figure 14
RV diastolic function	E/A: 0,8-2,1 and E/e'<6 http://www.parameterz.com/refs/eidem-jase-2004	Evaluation of RV diastolic function in adults. Z score for children.
LV systolic and diastolic function	E/A, E/e', LA dimensions http://www.parameterz.com/refs/dallaire-circimaging-2015	LV diastolic dysfunction may be the cause or secondary to RV overload
Cardiac shunt	E-D	Evaluate flow direction and pattern
Pulmonary artery acceleration time (ACT)	Pulmonary ACT index shortening (Z score <-2) is predictive of HP http://www.parameterz.com/refs/koestenberger-circimaging-2017	Correlates positively with weight, age, body surface, and negatively with heart rate. Figure 10
RV strain	Not established. There are publications reporting RV>-14% worse outcome	Potential predictor of outcome in pediatric patient with HP. Figure 15
RA strain	Not established. Publications report progressive worsening of atrial strain correlated with HP	Potential predictor of outcome in pediatric patient with HP. Figure 16

PASP= Pulmonary artery systolic pressure; MPAP= Mean pulmonary artery pressure; DPAP= Diastolic pulmonary artery pressure; TAPSE= Tricuspid annular plane systolic excursion; FAC= Right ventricular fractional area change; MPI= Myocardial performance index.

Authors' contribution

Research creation and design: Sawamura KSS. Data acquisition: Sawamura KSS, Leal GN, Morhy SS. Data analysis and interpretation: Sawamura KSS, Leal GN,Lianza AC, Morhy SS. Manuscript writing: Sawamura KSS. Critical revision of the manuscript for important intellectual content: Leal GN, Lianza AC, Morhy SS.

Conflict of interest

The authors declare that there is no conflict of interest regarding this manuscript.

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