Role of echocardiography in the assessment of right ventricular function in the pediatric population

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Abstract
This review article summarizes the use of echocardiography in the evaluation of the right ventricle with special emphasis on pediatric patients. After reading this article, anesthesiologists will develop a better understanding of the anatomy and echocardiographic parameters for hemodynamic and functional assessment of the right ventricle. This knowledge will assist with the perioperative management of patients with cardiopulmonary disorder.

KEYWORDS
adolescent, age groups, anesthesia, child, echocardiography, heart ventricles, infant

1 | INTRODUCTION

The right ventricle (RV), which has been abandoned in the past as merely a conduit chamber, is now recognized to perform a conspicuous role in the clinical outcome and functional status of a patient with a cardiopulmonary disease. For an anesthesiologist providing care to pediatric patients with cardiopulmonary disease, it is important to understand key echocardiographic parameters utilized to assess the hemodynamics, size, dimensions, and function of the RV. In conjunction with clinical information, echocardiographic data render pathophysiological information about the RV and facilitate optimal perioperative management of such patients.

2 | ANATOMY

As the anterior most chamber of the heart, the RV is located underneath the sternum. The thin-walled RV extends from the tricuspid valve (TV), which is situated inferiorly and rightward to the pulmonary valve (PV) placed leftward and superiorly. Spatially, the RV forms the inferior border of the heart. The RV has three main components: inlet portion that spans from the hinge point of TV to papillary muscle insertion in the ventricular wall, trabecular apical portion of RV that consists of coarse trabeculations extending all the way to the ventricular septum, and the smooth outlet portion that lies beyond the trabecular part and comprises of infundibulum supporting the PV leaflets.

The RV wraps around the left ventricle (LV), and the appearance varies depending on the cross-section and echocardiographic view. In mid-cavitary, parasternal short axis (SAX) view, the RV appears crescent-shaped. RV resembles a spade shape in the parasternal long axis (LAX) view and tubular in parasternal basal SAX view. In the four-chamber (4-Ch) view, it can have a triangular configuration. The septal position also impacts the shape of the RV under various loading conditions.

The arrangement of muscle fibers in the RV wall is different from the LV wall. The superficial layer of the RV wall is primarily formed by circumferential to obliquely oriented fibers. Sparse longitudinal fibers constitute the subendocardial layer of the RV wall. The septum is comprised of helical fibers. Circular fibers that form the intermediate layer of the LV wall are missing in the RV wall. However, the muscle fibers of both RV and LV are contiguous. The oblique fibers by lengthening and shortening account for about 80% of RV systolic function; whereas, the helical fibers attribute to about 20% of the RV systolic function. Hence, the RV contraction chiefly occurs in the longitudinal axis.

Tricuspid valve is composed of three leaflets: septal, antero-superior, and inferior/posterior leaflet. Inferior papillary muscle provides support to the septal and inferior/posterior TV leaflets. Medial papillary muscle reinforces inferior/posterior and
anterosuperior leaflets. The anterosuperior leaflet is anchored by anterior papillary muscle. The hinge point of the septal leaflet of the TV is closer to the ventricular apex in comparison to the anterior leaflet of the mitral valve. Also, the chordae supporting the septal leaflet extend to the right ventricular surface of the ventricular septum. A band of muscle between the RV body and the infundibulum called the septomarginal band or moderator band is unique to the RV. These features assist in distinguishing the morphologic RV from the morphologic LV. Finally, PV has three leaflets: anterior, right, and left cusps.

3 | BLOOD SUPPLY OF THE RV

Right ventricle receives its blood supply principally from the right coronary artery in both systole and diastole, distinguishing it from LV which is perfused predominantly by the left coronary system during diastole. Also, the blood supply to the diaphragmatic surface of the RV and posterior interventricular septum from the posterior descending/inferior interventricular artery is dependent on the dominance of coronary circulation. In the right dominant coronary system (incidence 85%), the posterior descending/inferior interventricular artery arises from the right coronary artery. In left dominant coronary system (incidence 7%), the posterior descending artery either receives branches just from the left circumflex or left anterior descending/anterior interventricular artery. In codominant coronary circulation (incidence 4%), the posterior descending artery receives branches from both right coronary and anterior interventricular or circumflex arteries. Other branches of the right coronary artery are infundibular or canal artery, atrial branches, artery to sinus node, right marginal artery, and atrioventricular nodal arteries.

4 | COMMON ECHOCARDIOGRAPHIC VIEWS FOR ASSESSMENT OF RV

The main transthoracic views used for the assessment of RV are outlined in the table below. Equivalent transesophageal views are listed in the second column. This article integrates both transthoracic and transesophageal echocardiographic views for RV evaluation.

| Transthoracic echocardiography          | Transesophageal echocardiography |
|----------------------------------------|---------------------------------|
| RV focused Apical 4-Ch                 | ME RV focused 4-Ch              |
| RV focused Apical 5-Ch                 | ME RV focused 5-Ch              |
| RV focused apical coronary sinus       | ME 4-C RV focused coronary sinus|
| RV focused parasternal LAX             | TG RV inflow                    |
| Parasternal SAX                        | TG RV/LV SAX                    |
| Parasternal RV inflow tract            | ME RV inflow/outflow            |
| Subcostal RV focused 4-Ch             | ME RV focused 4-Ch              |
| Subcostal SAX basal RV                 | TG RV/LV SAX                    |

5 | QUALITATIVE EVALUATION OF RV

5.1 | Interventricular septal morphology

Visual inspection of the interventricular septum can ascertain the RV volume as well as the pressure load in parasternal basal or mid SAX view, apical view, and subcostal 4-Ch view. Under normal conditions, the LV cavity appears circular in the parasternal SAX view as the LV pressure is higher than the RV pressure throughout the cardiac cycle.

The implication of significant RV pressure overload, as seen with pulmonary hypertension results in the RV pressure potentially being greater than the LV pressure during late systole and early diastole. This increased RV pressure causes a shift of interventricular septum in the direction of the LV culminating into a flat septum and a D-shaped LV during end-systole (at the end of T-wave) (Figure 1). Further increase in RV pressure will cause the septum to curve toward the LV.

Right ventricle volume overload, as seen with tricuspid and pulmonary regurgitation (PR), leads to increased RV pressure during mid-diastole, consequently shifting the septum toward the LV and to a D-shaped septum in diastole. The systolic conformation of the interventricular septum remains normal.

5.2 | Assessment of wall motion abnormalities

Visual examination of the wall motion abnormalities of RV is feasible by echocardiography. The RV wall can be divided into three main components: anterior, lateral, and inferior. On transthoracic echocardiography (TTE), the anterior RV wall can be visualized in parasternal mid-papillary SAX, RV inflow, LAX view of right ventricular outflow track (RVOT), and subcostal SAX basal RV views. We see the lateral RV wall in RV apical 5-Ch, apical 4-Ch, apical coronary sinus, and parasternal mid-papillary SAX views. Inferior wall of the RV is visible in the parasternal SAX at aortic valve and mid-papillary level, RV inflow, and subcostal 4-Ch views.

Transesophageal echocardiography (TEE) reveals the lateral wall of RV in ME 4-Ch and mid-papillary transgastric (TG) LV SAX view. We see the anterior wall of RV in TG RV inflow and mid-papillary LV SAX views. Inferior wall of RV is visible in ME RV inflow-outflow, TG RV inflow, and mid-papillary LV SAX views. The anterior wall of RVOT is seen in ME LV LAX view.1,2

6 | EVALUATION OF RV STRUCTURE

6.1 | Linear dimensions

Linear dimensions are obtained for the inflow and outflow regions of the RV. Inflow linear dimensions are ascertained in apical 4-Ch RV focused view on TTE and ME 4-Ch view on TEE. Inflow measurements comprise of basal and mid-cavity transverse diameter of the RV at end-diastole using the inner edge to inner edge method where the inner edge is the interface between the cavity of the chamber
and the first sign of endocardium. Inflow basal diameter is obtained parallel to the tricuspid annulus. Inflow mid-cavity diameter is retrieved at the level of papillary muscles.

Outflow linear dimensions are measured in parasternal LAX and SAX views on TTE. On TEE, ME RV inflow, deep transgastric (DTG) LAX, and DTG Sagittal views can be used to ascertain the same measurements. The measurements are gathered using the inner edge to inner edge method at end-diastole. In parasternal LAX view, the proximal RV outflow diameter is the distance between the anterior RV wall and the interventricular septum at the level of the aortic junction. In the parasternal SAX view, the distal RV outflow diameter is the distance measured from the anterior RV wall to the aortic valve just proximal to the PV.

### 6.2 | Area and fractional area change of RV

Right ventricle endocardial border is traced manually at end-diastole (first frame when mitral valve closes or peak R-wave on electrocardiogram mid esophageal (ECGME) or maximum ventricular volume) and end-systole (first frame when the aortic valve closes or end of T-wave on ECGME or minimum ventricular volume). This measurement provides the end-diastolic area (EDA) and end-systolic area (ESA). The trace starts from the lateral tricuspid annulus along the lateral wall of RV down to the apex and then along the interventricular septum ending at the medial annulus of the TV. The trace separates trabeculations, papillary muscles, and moderator band on the same side as the cavity of the ventricle; the remaining endocardium and all of the myocardium are outside of the same tracing (Figure 2). On TTE, fractional area change (FAC) is usually obtained in RV focused apical 4-Ch view. ME 4-Ch view with the focus on RV at 0-20° can also be used to capture FAC with TEE.

\[
\text{FAC RV in }\% = \left(\frac{\text{EDA} - \text{ESA}}{\text{EDA}}\right) \times 100
\]

In comparison to magnetic resonance imaging (MRI), 2D echocardiography can be limited in calculating the FAC in patients with congenital heart disease (eg repaired tetralogy of Fallot). The limitations exist due to complicated three-dimensional geometrical features of RV, the proximity of RV to the anterior wall and resultant artifact, and longitudinal rather than concentric motion of the fibers in RV.

### 6.3 | RV volume

Three-dimensional echocardiography is utilized to obtain RV volume at end-systole and end-diastole. RV volume measurements alter with age, gender, and body surface area (BSA). Hence, RV end-systolic volume (ESV) and end-diastolic volume (EDV) are indexed to BSA. These measurements are made in 4-Ch view on both TTE and TEE.

\[
\text{RV ejection fraction (RVEF)} = \left(\frac{\text{RV enddiastolic volume (RVEDV)} - \text{RV endsystolic volume (RVESV)}}{\text{RV enddiastolic volume (RVEDV)}}\right)
\]

A recent study by Laser et al comparing MRI with 3D echocardiographic assessment of right ventricular volume in children concluded that reliable and accurate RV volumetric assessment can be made by 3D echocardiography. The study also provided the reference percentile curves for clinical utilization in pediatric
Due to transducer size, the use of 3D transesophageal echocardiography is limited to older pediatric patients, and the weight-based use of 3D TEE probe is dependent on manufacturer's recommendations.

6.4 | RV wall thickness

Both 2D and M-mode can be utilized to measure the wall thickness of the RV at the level of the tip of the anterior leaflet of TV. Obtain the end-diastolic measurement in a region which is devoid of the trabeculations, papillary muscles, and moderator band. Subcostal 4-Ch view on TTE as well as ME 4-Ch with focus on RV and ME aortic valve LAX views on TEE are used to obtain this measurement.

Kampmann et al have published the normal M-mode echocardiographic measurements of RV wall thickness and RV end-diastolic dimensions based on BSA and body weight for nearly 2000 children. These parameters can be used as a reference for normal vs abnormal RV wall thickness measurements in children.

7 | HEMODYNAMIC ASSESSMENT OF RV

7.1 | Pulmonary artery systolic pressure

Pulmonary artery systolic pressure (PASP) can be predicted from the peak-systolic tricuspid regurgitation (TR) jet velocity using the modified Bernoulli's equation. PASP is equal to right ventricle systolic pressure (RVSP) in the absence of RVOT, PV and pulmonary artery stenosis.

\[
PASP = RVSP = 4 \times (\text{Maximum TR velocity})^2 + \text{Right atrial pressure (RAP)}
\]

This measurement is often obtained with TTE in both RV inflow view or apical 4-Ch view by utilizing continuous wave Doppler, in
order to ensure that the TR velocity is not underestimated. (Figure 3) During TEE it can be measured in the ME 4-Ch view.

7.2 | Right atrial pressure

The three parameters described below provide an estimate of the right atrial pressure in adult population. However, the validity of inferior vena cava (IVC) collapsibility index and hepatic vein systolic filling fraction as an estimate of mean right atrial pressure (RAP) is questionable in pediatric population. A recent study by Arya et al concluded that these parameters were not associated with mean right atrial pressure in pediatric patients with pulmonary hypertension and heart transplantation. However, the study found a reasonable relationship between right atrial volume and mean right atrial pressure in this group of patients. This study excluded the patients with structural heart disease except for small atrial septal defect, hematocrit less than 30%, and nonsinus rhythm.5

7.2.1 | IVC diameter and collapse

Inferior vena cava diameter and its collapse with inspiration due to the negative intrathoracic pressure in a spontaneously ventilating patient help to determine the mean right atrial pressure. Increased right atrial pressure results in a dilated and a less collapsible IVC with respiration. Two-dimensional imaging in the subcostal LAX view of IVC is utilized to obtain these measurements. These measurements are made during normal respiration and with sniffing just before the entrance of IVC into the right atrium. In the adult population, RAP is low (<5 mm of Hg) if the IVC diameter is <2 cm with a collapse of >50% with a sniff. RAP is high (15 mm Hg) if the IVC diameter is >2 cm with a collapse of <50% with a sniff. M-mode can also be used to acquire IVC diameter. Severe TR can lead to systolic flow reversal in the IVC on color Doppler. However, in intubated patient and for intermediate right atrium (RA) pressures, invasive central line pressure is more accurate than the IVC diameter method.

7.2.2 | Hepatic vein velocity

In TTE, the hepatic vein flow velocity profile is acquired in the subcostal view using pulsed wave Doppler. It has a retrograde A-wave above the baseline that occurs during the atrial systole due to movement of blood toward the liver. It commences with the P-wave and peaks with the QRS complex on ECGME. The A-wave is followed by an anterograde S-wave below the baseline during ventricular systole. The S-wave occurs due to the movement of blood from the liver to the right atrium created by tricuspid annulus motion toward the cardiac apex in systole. During spontaneous respiration, the passive flow of blood from the liver into the heart during diastole translates into anterograde D-wave below the baseline. The D-wave occurs after the T-wave during diastole on ECGME. With normal RAP, systolic wave velocity (V_s) is greater than diastolic flow velocity (V_d). With increased RA pressure, the difference between the two decreases and eventually reverses. Hepatic vein systolic filling fraction is defined as $V_s/(V_s + V_d)$. Elevated RA pressure is associated with a hepatic vein systolic filling fraction less than 55%.

7.2.3 | Atrial septal position

The position of the right atrial septum can provide an estimate of RAP in comparison to left atrial pressure (LAP). If the atrial septum is bulging toward the left atrium, then RAP is greater than LAP.6,7

7.3 | Pulmonary artery diastolic pressure

In TTE, the pulmonary artery diastolic pressure (PADP) is derived from the PR jet velocity that is acquired in parasternal and subcostal SAX views. Color Doppler at the level of the PV in these views shows systolic blue (away) flow going from RVOT into the pulmonary artery through the PV. PR blood flow in this view appears red. In spectral Doppler, this PR flow occurs during diastole and is above the baseline.

$$PADP = [4 \times (PR \text{ end diastolic velocity})^2] \times RAP$$

7.4 | Mean pulmonary artery pressure

Mean pulmonary artery pressure (mPAP) can also be derived from PR velocity where

$$mPAP = [4 \times (early \text{ peak PR velocity})^2] + RAP$$

Mean pulmonary artery pressure can also be obtained from pulmonary artery forward flow during systole. This measurement is made at end-expiration. PW Doppler is placed just distal to the PV in parasternal SAX. Pulmonary artery acceleration time (PAAT) is defined as the time of initiation of ejection to the peak flow velocity.

$$mPAP = 79 - (0.45 \times PAAT)$$

7.5 | Pulmonary vascular resistance

Pulmonary vascular resistance (PVR) can be deduced from maximum TR velocity (VTR_max) and velocity time integral of the RVOT. Continuous wave (CW) Doppler is used to capture the TR trace. VTR_max is measured. Velocity time integral (VTI) of the RVOT (VTI_RVOT) is obtained with PW Doppler of systolic flow just proximal to the PV in parasternal SAX view. The following equation to estimate PVR was extracted from a linear regression analysis between cardiac catheterization derived PVR vs VTR_max/VTI_RVOT deduced from echocardiography.8

$$PVR = \left[ \frac{VTR_{max}}{VTI_{RVOT}} \times 10 \right] + 0.16$$
8 | EVALUATION OF FUNCTION OF RV

The following parameters are used in the assessment of RV function.

8.1 | Myocardial performance index of the RV

Tei index or RV index of myocardial performance or MPI of the RV is the index that assesses the global systolic and diastolic RV function. Pulsed, continuous, and tissue Doppler can be used to capture this index.

\[
\text{MPI} = \frac{(\text{Tricuspid closure to opening time} - \text{RV ejection time})}{\text{RV ejection time}}
\]

In the pulsed wave Doppler method, tricuspid closure to opening time (TCO) is obtained from TV inflow timing. TCO is the time between the end of A-wave and beginning of the next E-wave. TR jet tracing obtained by continuous wave Doppler can also be used to derive TCO by measuring the TV closure to the opening from the TR jet. RV ejection time (RVET) is the time from onset of the ejection to the end of ejection and can be measured in parasternal SAX or RV outflow view using PW or CW Doppler. Subtracting the RVET from TCO derives the sum of the isovolumic relaxation time (IVRT) and isovolumic contraction time (IVCT). As these measurements are obtained in more than one beat, care must be taken to use similar RR interval.

Tissue Doppler can be used at the level of lateral tricuspid annulus on the RV wall to obtain the RVET, which is the duration of the systolic S’ velocity. IVRT is the time between the cessation of systolic S’ velocity and beginning of diastolic E’ velocity. These measurements are all obtained in a single beat. IVCT is the duration between the cessation of A’ wave and onset of S’ wave (Figure 4).

In pediatric population, tissue Doppler-derived RV index of myocardial performance alters with BSA; whereas, the RV MPI extracted from the pulsed wave Doppler is affected by patient’s age. In pediatric patients, tissue Doppler-derived MPI index of RV is approximately 0.37 ± 0.05; whereas MPI index derived from pulsed wave Doppler is 0.34 ± 0.06. RV MPI can be influenced by acute loading conditions. In a pediatric study, right ventricular MPI in patients with idiopathic pulmonary hypertension was found to be around 0.64 ± 0.30.9

8.2 | Tricuspid annular plane systolic excursion

Tricuspid annular plane systolic excursion (TAPSE) utilizes zoomed M-mode echocardiography to evaluate the longitudinal function of the RV by measuring the movement of the tricuspid annulus in the lengthwise direction during systole. On TTE, this measurement is obtained in apical 4-Ch view. During TEE, this measurement is made in ME 4-Ch view, TG RV inflow-outflow view, or DTG 4-Ch view. Place the M-mode cursor on the lateral tricuspid annulus. The M-mode cursor should be perpendicular to the TV annulus which will align with cardiac motion. Then, the TAPSE measures the distance between the minimum (peak-systolic) and maximum (end-diastolic) excursion of the TV. (Figure 5A) TAPSE is not altered by the changes in heart rate. However, sternotomy, pericardiotomy, and cardiopulmonary bypass can contribute to a reduction in TAPSE. Koestenberger et al have published reference values of TAPSE in pediatric patients based on their age and BSA.10

8.3 | Tissue Doppler imaging for longitudinal motion

Tissue Doppler imaging (TDI) is done in apical 4-Ch view with the focus on RV. TDI measures low frequency and high amplitude echoes generated by the myocardium. Highest myocardial velocities are obtained at the base of the ventricle. Both PW and color tissue Doppler can be

![Figure 4](image-url)
utilized. TDI at the lateral tricuspid annulus determines the longitudinal function of the RV. PW TDI Doppler of the TV is composed of positive S′ (systolic) velocities aligned toward the transducer in transthoracic echocardiography and negative diastolic E′ (early diastolic) and A′ (atrial contraction) velocities away from the transducer. (Figure 5B) In TEE, the Doppler signals will be inverted. Color Doppler 2-D TDI demonstrates red velocities that are moving toward the transducer in systole and blue velocities moving away from the transducer in diastole. Color-coded 2-D TDI enables concurrent assessment of multiple segments of RV. Like pulsed-wave Doppler, color TDI is also angle dependent so every attempt should be made to ensure that the Doppler samplings are parallel to tissue motion. An apical 4-Ch view is used to measure TDI with a focus on the RV. Then, the depth is adjusted to display the entire RV, tricuspid annulus, and part of the right atrium. Subsequently, the pulsed-wave Doppler button is used to sample at the level of the lateral tricuspid annulus. If a TDI setting is available on the ultrasound equipment, it should be utilized to optimize the signal quality. Velocity scale, baseline, gain, and filter are adjusted for optimal display of spectral Doppler waveforms. Every attempt should be made to ensure that the angle of incidence is less than 30°. A frame rate of over 140 Hz for color Doppler can be achieved by decreasing the depth and width of the sector. The data should encompass over three beats.

In pediatric patients, longitudinal S′ and E′ were found to have a positive correlation with age. A′ had a correlation with heart rate. Z-scores accounting for age, HR and BSA are available as a reference for TDI of longitudinal motion and serve as an important tool in estimating ventricular function. 

### 8.4 | dp/dT of the RV

The dp/dT of RV, an index of ventricular systolic function, is defined as the rate of rising of RV pressure during the isovolumetric contraction phase of ventricular systole. Continuous wave Doppler profile of TR is used to acquire dp/dT of RV. The point of measurement is the rate of increase in TR velocity from 1 to 2 m/s or increase in pressure of 12 mm Hg [4 × (2)² – 4 × (1)²]. The dp/dT is the amount of time taken by the RV to generate this pressure difference and is measured by taking 12 mm Hg divided by the time it takes to change the velocity from 1 to 2 m/s; the values are measured in mm Hg/s. Normal value of dp/dT for RV is 100-250 mm Hg/s. Lower values indicate dysfunction of the ventricle. This is a load-dependent parameter and can be inaccurate in severe TR.

### 8.5 | Strain and strain rate

Tissue Doppler and speckle tracking is used to capture the deformation parameters such as strain (degree of myocardial deformation) and strain rate (rate of deformation of myocardium over time) to evaluate RV function. (Figure 6) Since they are altered to a less extent by the volume loading conditions, strain and strain rate are used to evaluate the regional RV dysfunction. Normal ranges of RV strain are available in children.

### 9 | ROLE OF ECHOCARDIOGRAPHY IN DIAGNOSING AND MANAGING INTRAOPERATIVE RV FAILURE

Echocardiography, in collaboration with other clinical and invasive hemodynamic parameters, can assist the anesthesiologists in differential diagnosis and management of the etiology of RV failure. Intraoperative acute RV dysfunction can be a consequence of the acute increase in preload or decreased diastolic filling of RV, decreased RV contractility, and increased afterload.

### 9.1 | Assessment of preload

Intraoperative volume overload can be a result left to right shunts, valvular regurgitation, and iatrogenic administration of excessive fluids.
The right atrial pressure or central venous pressure, baseline fluid status and fluid responsiveness can be estimated by measuring the superior vena cava (SVC) and IVC diameters, respirophasic variation in diameters of SVC and IVC, distensibility index of IVC and collapsibility index of SVC. However, the echocardiographic parameters should be aligned with clinical status and invasive monitoring to gauge the preload. Based on the assessment, the anesthesiologists can prevent hypovolemia and volume overload.

9.2 | Assessment of diastolic filling

Real-time assessment of right ventricular diastolic filling may be done by examining the right atrial size compared to the left atrial size and a shift of the interatrial septum leftward toward the left atrium. In the setting of an atrial communication, a right to left shunt by color Doppler may be present. Late diastolic flow reversal in the hepatic veins may be present with diminished right ventricular compliance. These measures in conjunction with direct central venous pressure measurement can help to gauge the diastolic function of the RV.

9.3 | Assessment of contractility

Ischemia resulting from coronary hypoperfusion impairs RV function. Decline in perfusion pressure secondary to arrhythmias, hypotension, and decreased LV function, and metabolic abnormalities also negatively impact RV contractility.

Subjective evaluation of RV function as normal, mild, moderate, or severely depressed can be performed in tandem with quantitative parameters elucidated previously. Dobutamine, milrinone or low dose epinephrine can assist with primary RV dysfunction. Vasopressin and norepinephrine may play a role in managing low perfusion pressure culminating from systemic hypotension.

9.4 | Assessment of afterload

Right ventricle failure may also be a corollary to increased afterload precipitated by increased PVR, pulmonary embolism, and outflow tract obstruction.

Pulmonary artery systolic pressure is estimated from TR jet velocity. Early-diastolic and end-diastolic velocities from the PR jet provides an approximation of mean and diastolic pulmonary artery pressure, respectively. Besides the parameters highlighted above, the other clues for assessment of increased afterload are:

1. **RV:LV diameter ratio**

   End-systolic RV:LV diameter ratio greater than 1 in parasternal SAX view (TTE) or TG SAX (TEE) view at the level of papillary muscle signifies compression of LV by hypertensive RV in pulmonary hypertension patients. This ratio has minimal value in patients with volume-loaded ventricle secondary to the left to right shunt and severe PR.

2. **LV eccentricity index**

   Left ventricle eccentricity index is the ratio of the anteroposterior and septolateral diameters of LV cavity measured in parasternal SAX view (TTE) or TG SAX (TEE) view at the level of papillary muscle. The normal end-systolic and end-diastolic LV eccentric index is 1. This value increases to more than 1 in patients with pressure or volume overload on the RV. Along with diastolic septal
flattening, increased LV eccentricity index is used for risk stratification in pulmonary hypertension.

Elevated PVR resulting in increased afterload can be treated by improving ventilation strategies and inhaled and intravenous pulmonary vasodilators. Other contributing factors to increased afterload may require interventional or surgical procedures.

10 | SUMMARY

This review highlights the use of transthoracic and transesophageal echocardiography for the evaluation of the RV. The anesthesiologists taking care of pediatric patients with cardiac disease can improve clinical care by familiarizing themselves with the views, methodology, and pitfalls of various echocardiographic parameters utilized for the assessment of the RV.

Reflective questions

1. What is the pattern of interventricular septal motion in right ventricle (RV) pressure overload?
2. Anatomically, how many parts can the RV be divided into?
3. In a patient with a small patent foramen ovale, the tricuspid regurgitant velocity was calculated as 4 m/s. Assuming a RA pressure of 5 mm Hg, what will be the RV systolic pressure?
4. What is tricuspid annular plane systolic excursion?

DISCLOSURES

None.

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REFERENCES

1. Kossaify A. Echocardiographic assessment of the right ventricle, from the conventional approach to speckle tracking and three-dimensional imaging, and insights into the “right way” to explore the forgotten chamber. Clin Med Insights Cardiol. 2015;9:65-75.
2. Tan CO, Harley I. Perioperative transesophageal echocardiographic assessment of the right heart and associated structures: a comprehensive update and technical report. J Cardiothorac Vasc Anesth. 2014;28:1100-1121.
3. Laser KT, Karabiýik A, Körperich H, et al. Validation and reference values for three-dimensional echocardiographic right ventricular volumetry in children: a multicenter study. J Am Soc Echocardiogr. 2018;31:1050-1063.
4. Kampmann C, Wiethoff CM, Wenzel A, et al. Normal values of M mode echocardiographic measurements of more than 2000 healthy infants and children in central Europe. Heart. 2000;83:667-672.
5. Arya B, Kerstein D, Leu C-S, et al. Echocardiographic assessment of right atrial pressure in a pediatric and young adult population. Pediatr Cardiol. 2016;37:558-567.
6. Scheinfeld MH, Bilali A, Koenigsberg M. Understanding the spectral Doppler waveform of the hepatic veins in health and disease. Radiographics. 2009;29:2081-2098.
7. Rudski LG, Lai WW, Afiflalo J, et al. Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and the Canadian Society of Echocardiography. J Am Soc Echocardiogr. 2010;23: 685-713; quiz 86-88.
8. Jone PN, Ivy DD. Echocardiography in pediatric pulmonary hypertension. Front Pediatr. 2014;2:124.
9. Roberson DA, Cui W. Right ventricular Tei index in children: effect of method, age, body surface area, and heart rate. J Am Soc Echocardiogr. 2007;20:764-770.
10. Koestenberger M, Nagel B, Ravekes W, et al. Reference values and calculation of z-scores of echocardiographic measurements of the normal pediatric right ventricle. Am J Cardiol. 2014;114:1590-1598.
11. Mor-Avi V, Lang RM, Badano LP, et al. Current and evolving echocardiographic techniques for the quantitative evaluation of cardiac mechanics: ASE/EAE consensus statement on methodology and indications endorsed by the Japanese Society of Echocardiography. J Am Soc Echocardiogr. 2011;24:277-313.
12. Roberson DA, Cui W, Chen Z, Madronero LF, Cuneo BF. Annular and septal Doppler tissue imaging in children: normal z-score tables and effects of age, heart rate, and body surface area. J Am Soc Echocardiogr. 2007;20:1276-1284.
13. Levy PT, Sanchez Mejia AA, Machefsky A, Fowler S, Holland MR, Singh GK. Normal ranges of right ventricular systolic and diastolic strain measurements in children: a systematic review and meta-analysis. J Am Soc Echocardiogr. 2014;27(5):549-560, e3.

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