Basic Assessment of Right Ventricular Function

José L. Díaz Gómez

Resumen
La disfunción ventricular derecha es una entidad que merece ser bien caracterizada en el paciente crítico para tratarse de manera adecuada. Los hallazgos ecocardiográficos como el aumento del tamaño e hipocinesia ventriculares son fundamentales en esta evaluación inicial. En contraste, el ventrículo izquierdo puede parecer hiperdinámico frecuentemente. La evaluación ecocardiográfica del ventrículo derecho puede ser difícil debida a las complejas características anatómicas del mismo (pared libre ventricular irregular y localización en el tórax debajo del esternón) así como su particular mecanismo de contracción. Adicionalmente el papel del septo interventricular es vital en la adecuada función ventricular y repercusión en la función ventricular izquierda. Los evaluación ecocardiográfica inicial incluyen los parámetros cualitativos de la función ventricular derecha. Las medidas cuantitativas también deben ser incluidas en la valoración de pacientes con disfunción ventricular derecha para tener un seguimiento más objetivo. Finalmente, la distinción de los patrones ecocardiográficos de la sobrecarga de volume y presión ventricular derechas son valiosas en el momento de definir la estrategia de manejo médico.

Palabras Clave: Disfunción ventricular derecha, la ecocardiografía transtorácica, de choque, los ultrasonidos focalizados, sobrecarga del ventrículo derecho

Abstract
Right ventricular dysfunction is an entity that deserves to be better characterized in the critically ill patient in order to guide the medical management. Echocardiography findings such as right ventricular enlargement and hypokinesis are pivotal in this initial evaluation. In contrast, often times the left ventricle may appear hyperkinetic. The echocardiographic evaluation of the right ventricle might be challenging due to its complex anatomic characteristics (irregular free wall and localization under the sternum) as well as its peculiar mechanism of ventricular contraction. In addition, the role of the interventricular septum is crucial in the adequate ventricular function and repercussion in the left ventricular dysfunction. An initial echocardiographic evaluation includes qualitative parameters. However, quantitative parameters should be used to guide more appropriately the medical management. Finally, the distinction between volume and pressure overloading is important at the time to define the treatment
Focused Echocardiography and Right Ventricular Function

Right ventricular failure is characterized by echocardiographic changes including an enlarged and hypokinetic right ventricle. At times the left ventricle appears hyperdynamic.

The echocardiographic evaluation of the right ventricle is limited by its complex anatomy and its anterior location under the sternum. (1) The free wall irregular endocardial surface due to its trabeculation makes edges recognition difficult. The right ventricle contraction mechanism is considered complex also. It depends on both the free wall and interventricular septum. For these reasons, the identification of a reliable and accurate echocardiographic parameter for the assessment of the right systolic ventricular function still remains elusive. (2, 3)

Evaluating Right Ventricular Dysfunction

Estimation of the right ventricle dimension and function can be done utilizing M mode and 2-D echocardiography in the following views: subcostal, apical and parasternal long axis as well as short axis at the level of midpapillary muscles. The optimal acquisition of right ventricle views is obtained in approximately 50% of cases.

Dimension

• Absolute

The right ventricle has a recognized crescent shape, thin wall, and two functional-structural parts, the inflow and outflow tracts. Two-dimensional echocardiography is a well-characterized cardiac evaluation. (Figures 1 and 2). (4) However, two-dimensional echocardiography is a limited method to assess the right ventricle because its complex anatomy. Moreover, there is not a definitive three-dimensional evaluation of the right ventricle despite simplifications of its shape. The utilization of the Simpson’s formula, which is based in geometric assumptions of the right ventricle, can be inaccurate for calculation of the right ventricular ejection fraction. Therefore, surrogate quantitative methods to assess right ventricular function have been developed and validated against the ejection fraction. (3, 5) Diameter measurement using M-mode are time saving and applicable by less experienced operators if high image quality is obtained. (6)

Based in geometric assumptions, some quantitative methods to assess the right ventricular function are available.
1) Right ventricular size using dimensions: Apical view. Measurements should be performed at end of diastole and the appropriate alignment should be obtained. D1: chamber length, D2: measurement at mid ventricular level, D3: minor axes measurement at the level of tricuspid annulus. (Figure 1)

Table 1. Normal right ventricular dimensions

<table>
<thead>
<tr>
<th>Degree of RV Dilation</th>
<th>Normal Range</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basal RV dimension</td>
<td>2.0-2.8</td>
<td>2.9-3.3</td>
<td>3.4-3.8</td>
<td>≥ 3.9</td>
</tr>
<tr>
<td>Mid RV dimension</td>
<td>2.7-3.3</td>
<td>3.4-3.7</td>
<td>3.8-4.1</td>
<td>≥ 4.2</td>
</tr>
<tr>
<td>RV length</td>
<td>7.1-7.9</td>
<td>8.0-8.5</td>
<td>8.6-9.1</td>
<td>≥ 9.2</td>
</tr>
</tbody>
</table>


Figure 1. Right ventricle with normal dimensions. A. Apical 4-chamber view. B. Parasternal, long-axis view.

Figure 2. Right ventricle with increased dimensions. Parasternal, long-axis view. Increased measurement of the RV outflow tract.
The right ventricular area change (RVFAC), is a surrogate of RV ejection fraction and express the percentage change in RV area between end-diastole and end systole. RVFAC is predictive of outcome in patients with pulmonary hypertension and myocardial infarction.(7) It is calculated as follows:

RVFAC = \frac{RV \text{ end-diastolic area (cm}^2\text{)} - RV \text{ end-systolic area (cm}^2\text{)}}{RV \text{ End-Diastolic Area}} \times 100

This measurement is a practical method of assessing RF function and it depends on the optimal definition of the at the anterior RV wall. Right ventricular areas can be very altered by inherent operator tracing and morphological changes of the RV in patients with long-standing pulmonary hypertension. In addition, there is important overlapping of measurement between normal and volume overloaded RV. (6)

2) Right ventricular size using planimetry: Apical view.

Table 2. Normal right ventricular volumes

<table>
<thead>
<tr>
<th>Degree of RV Dilation</th>
<th>Normal Range</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV end-diastolic area (cm²)</td>
<td>11 – 28</td>
<td>29 – 32</td>
<td>33 – 37</td>
<td>≥ 38</td>
</tr>
<tr>
<td>RV end-systolic area (cm²)</td>
<td>7.5 – 16</td>
<td>17 – 19</td>
<td>20 – 22</td>
<td>≥ 23</td>
</tr>
<tr>
<td>Fractional area change (%)</td>
<td>32 – 60</td>
<td>25 – 31</td>
<td>18 – 24</td>
<td>≥ 17</td>
</tr>
</tbody>
</table>


- Comparative
  The comparative evaluation can be more meaningful due to the contribution of the left ventricle, interventricular septum and intrapericardial pressure to the right ventricle function.
  Under normal conditions the right ventricle should be two-thirds of the left ventricle size in at least two views. (8) (Figure 3)

Figure 3. Right ventricle dysfunction – RV dimensions. Severe enlargement of right ventricle.
The visualization of the right ventricular function should be considered as an overall qualitative assessment from multiple echo views. Both global and regional wall motion abnormalities can be documented depending on the etiology of RV dysfunction. (4)

**Table 3. Etiology of right ventricular dysfunction and echocardiographic pattern**

<table>
<thead>
<tr>
<th>Global right ventricular dysfunction</th>
<th>Regional wall motion abnormalities in RV dysfunction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute pulmonary embolism</td>
<td>Acute pulmonary embolism</td>
</tr>
<tr>
<td></td>
<td>• McConnell sign: akinesia of the basal and mid free wall – normal motion at the apex</td>
</tr>
<tr>
<td>Septic shock</td>
<td>Acute inferior myocardial infarction – 50% present RV infarction</td>
</tr>
<tr>
<td></td>
<td>• Free wall</td>
</tr>
<tr>
<td></td>
<td>• McConnell sign:</td>
</tr>
<tr>
<td>Chronic pulmonary hypertension</td>
<td>Regional cardiac tamponade</td>
</tr>
<tr>
<td></td>
<td>• RV diastolic collapse</td>
</tr>
<tr>
<td>Post-open heart surgery (reduced RV long axis motion as a common finding)</td>
<td></td>
</tr>
</tbody>
</table>

• Measured
  
  **Tricuspid Annular Plane Systolic Excursion (TAPSE)**

The RV wall motion pattern is composed mainly by two components: longitudinal shortening from base to apex and radial shortening to the apex. (9) The first component is the main factor to determine TAPSE. It is a one-dimensional approach, reflection regional but not global, right ventricular systolic function. Indeed, it refers to the quantitative assessment of the tricuspid valve motion during systole. It is better measured in the apical four-chamber view. M-mode imaging technique is applied to determine TAPSE with the cursor passed through the tricuspid lateral annulus. The normal value of TAPSE is between is 1,5 - 2 cms. TAPSE values less than 1,5 to 2 cms can predict RV dysfunction associated to clinical conditions such as pulmonary embolism, heart failure and myocardial infarction. (3, 8, 10) In contrast, it has been considered inaccurate in the assessment of RV function after cardiac surgical procedures. Although a clear etiology has not been identify, it is probably due to the interpretation of a longitudinal parameter in a patient population undergoing cardiac surgery procedures that affect the entire heart motion. (11) One of the important limitations of the TAPSE is the influence of the left ventricle functional status (another factor to take into account) when interpreting this longitudinal study. (12)

**Figure 4. Tricuspid Annular Plane Systolic Excursion (TAPSE). Normal value in the setting of chronic enlarged RV.**
**o Peak Systolic velocity – tissue Doppler**

The quantification of tissue Doppler velocity over the lateral annulus has been demonstrated to be useful and relatively simple non-invasive correlate of right ventricular function. (6) An abnormal value of peak velocity is considered less than 9 to 10 cm/sec and it can be suggestive of right ventricular dysfunction. (8, 13)

Furthermore, his parameter has shown to be an independent predictor of right ventricular infarction in the setting of acute inferior myocardial infarction. (14, 15, 16)

![Figure 5. Peak Systolic velocity – tissue Doppler. Normal velocities in the setting of chronic enlarged RV.](image)

**Figure 5. Peak Systolic velocity – tissue Doppler. Normal velocities in the setting of chronic enlarged RV.**

**Septum**

The septal motion is considered a major determinant of the right ventricular function under normal conditions and pathological states. (17)

- **Right ventricular overload**

Right ventricular overload can be caused by both pressure and volume strain.

- **o Volume**

Right ventricular volume overload is better represented by dilatation of the right ventricle. The right ventricular area in diastole should be approximately two-thirds of the left ventricle. A qualitative criterion of right ventricular volume overload is an area equal or greater than the left ventricular area in diastole. (8) The appearance of the septum helps to characterize volume overload. The crescent shape of the RV is lost and the septum becomes flat in the setting of volume overload. The left ventricle takes the shape of the letter "D". (3)

In this condition, the septum flattens predominantly in diastole. Thus the right ventricle appears to be more spherical.

**o Pressure**

Chronic elevation of the pulmonary artery pressure imposes an increased afterload to the right ventricle and subsequent hypertrophy. However, the measurement of the degree of right ventricle free wall hypertrophy is challenging due to the presence of trabeculation. The best approach to overcome this difficulty is the utilization of the parasternal long axis view with medial angulation. (18) It exposes the epicardial and endocardial surfaces. However, the RV free wall thickness is most reliably measured in the subcostal view and normally measures 3.4 ± 0.8 mm. (3)

The appearance of the septum helps to characterize volume overload. In this condition, the septum flattens in systole and diastole.

Doppler imaging is an important complementary tool to assess right ventricular pressure overload. The peak pulmonary earlier velocity is commonly present in right ventricular pressure overload. Likewise the measurement of the time to achieve the peak velocity (acceleration time for systolic flow) is a surrogate of higher pulmonary artery pressure. Mean pulmonary artery pressure can be estimated using the regression equation: 80 -0.5(acceleration time). (4)
The more commonly used measurement of right ventricular pressure is the estimation of tricuspid regurgitation jet velocity. Then, the Bernoulli equation is used to estimate the right ventricular systolic pressure (RVSP) as follows. (4, 18, 19)

\[
RVSP = 4 \times (\text{Tricuspid regurgitation velocity})^2 + \text{Right atrial pressure}
\]

The RVSP is a rapid method to assess pulmonary hypertension since the pulmonary artery and right ventricular pressure are similar. (20)

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**Echocardiographic sections for the evaluation of right ventricular function**

<table>
<thead>
<tr>
<th>Echocardiographic view</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parasternal long axis view</td>
<td>End-diastolic diameter of RVOT (2D-M-mode)</td>
</tr>
<tr>
<td>Parasternal short axis – basal view</td>
<td>• End-diastolic and end-systolic diameters of RV outflow tract</td>
</tr>
<tr>
<td></td>
<td>• RVOT shortening fraction</td>
</tr>
<tr>
<td>Apical four-chamber view</td>
<td>• RV long and short axis diameters, D1: basal RV measurement; D2: mid-RV measurement; D3: base-to-apex measurement.</td>
</tr>
<tr>
<td></td>
<td>• TAPSE (M-mode cursor through tricuspid annulus as parallel as possible). Decrease gain and sweep speed of 75-100 mm/s optimizes the technique.</td>
</tr>
<tr>
<td></td>
<td>• Peak systolic velocity – tissue Doppler (pulse Doppler of the basal RV wall in systole)</td>
</tr>
<tr>
<td></td>
<td>• RV fractional area change. Optimize imaging decreasing the depth or using the zoom function.</td>
</tr>
<tr>
<td>Subcostal view</td>
<td>RV free wall thickness. Obtained at end of diastole at the level of chordae tendineae.</td>
</tr>
</tbody>
</table>

Ideally, all images acquisition should be done under apnea (or smooth respiration) for 2D measurements. (21)
Tips #1
- Right ventricular systolic dysfunction can be determined by the change in RV dimensions and area by 2-D echocardiography.
- Severe tricuspid regurgitation by continuous wave Doppler is characterized by a dense signal with early peaking.

Tips #2
- In cases of right ventricular volume overload, the interventricular septum flattens predominantly in diastole.
- In cases of right ventricular pressure overload, the interventricular septum flattens in both systole and diastole.

RIGHT VENTRICULAR DYSFUNCTION PATTERN INDICES

COMMON PITFALLS

The assessment of the right ventricular function is difficult in patients with prior cardiothoracic surgery or have chronic lung disease. (20)

Edge recognition of the right ventricle is difficult due to the extensive trabeculation the right ventricular free wall. The presence of the moderator band within right ventricle apex is a normal finding. (20)

Chronic pulmonary hypertension commonly causes changes in the morphology of the right ventricle (hypertrophy and right chambers enlargement). These findings should be taken in consideration with surrogates of cardiac function such as measurement of cardiac index or mixed venous oxygen saturation. Some patients might maintain a low normal or normal right ventricular function despite increased dimensions.
Clinical Cases

39 yo woman G3P1, 22 weeks, with 3-4 weeks of progressive dyspnea. Over last 48h she presented severe dyspnea to the point where she was symptomatic at rest. Patient was admitted to the ICU and oxygen therapy initiated with non-rebreathing mask. She also had elevated LFTs and hemolysis, concerning for HELLP. After discussion with the high risk OB service, it was decided to terminate the pregnancy. An echocardiogram was performed within ICU.

![Echocardiogram Images](image)

**Figure 7. Clinical Case – respiratory failure and HELLP syndrome.**
A and B. Severely dilated right ventricle. Severe Tricuspid regurgitation with estimated RVSP at least >70 mmHg. C. Under-filled left ventricle and D shaped septum with systole and diastole. D. Severely dilated with moderate hypertrophy of right ventricle.

She developed oliguria and a PAC was inserted under fluoroscopy guidance which showed RA20 PA 100/40s (mean 66), CO 2.73.

**Conclusión**

La valoración de la función ventricular derecha es importante en el manejo médico de pacientes críticamente enfermos. La ecocardiografía transtorácica es una herramienta válida en esta evaluación objetiva de la función ventricular. Los parámetros cualitativos y cuantitativos deben ser tenidos en cuenta para el seguimiento clínico y guiar la terapia médica. La distinción de la sobrecarga ventricular de presión y volume ayudan a guiar el manejo médico igualmente.

**References**


