Assessment of Right Ventricle Size, Function, and Hemodynamics

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GUIDELINES AND STANDARDS

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

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(J Am Soc Echocardiogr 2010;23:685-713.)

GUIDELINES AND STANDARDS

Recommendations for Cardiac Chamber Quantification by Echocardiography in Adults: An Update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging

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Importance of RV Dysfunction in Various Disease States

- Primary Pulmonary Arterial Hypertension
- Pulmonary Thromboembolism
- Secondary
  - Left heart failure
  - Left sided valve diseases
  - Myocardial infarction with RV involvement
- Congenital Heart Diseases
- ARVD/Other Systemic Diseases
2D Assessment

*Right ventricle*

- Structurally complex cavity:
  - crescent shape
  - irregular endocardial surface due to heavy trabeculation: difficult to delineate endocardial border
  - location behind the sternum: inadequate image quality

- Fits no simple geometric figure:
  - failure to standardize RV volume determination

- RV size estimation requires integration of multiple views and qualitative and quantitative assessment
<table>
<thead>
<tr>
<th>Dimension</th>
<th>Studies</th>
<th>n</th>
<th>LRV (95% CI)</th>
<th>Mean (95% CI)</th>
<th>URV (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV mid cavity diameter (mm) (Figure 7, RVD2)</td>
<td>12</td>
<td>400</td>
<td>20 (15-25)</td>
<td>28 (23-33)</td>
<td>35 (30-41)</td>
</tr>
<tr>
<td>RV basal diameter (mm) (Figure 7, RVD1)</td>
<td>10</td>
<td>376</td>
<td>24 (21-27)</td>
<td>33 (31-35)</td>
<td>42 (39-45)</td>
</tr>
<tr>
<td>RV longitudinal diameter (mm) (Figure 7, RVD3)</td>
<td>12</td>
<td>359</td>
<td>56 (50-61)</td>
<td>71 (67-75)</td>
<td>86 (80-91)</td>
</tr>
<tr>
<td>RV end-diastolic area (cm²) (Figure 9)</td>
<td>20</td>
<td>623</td>
<td>10 (8-12)</td>
<td>18 (16-19)</td>
<td>25 (24-27)</td>
</tr>
<tr>
<td>RV end-systolic area (cm²) (Figure 9)</td>
<td>16</td>
<td>508</td>
<td>4 (2-5)</td>
<td>9 (8-10)</td>
<td>14 (13-15)</td>
</tr>
<tr>
<td>RV end-diastolic volume indexed (mL/m²)</td>
<td>3</td>
<td>152</td>
<td>44 (32-55)</td>
<td>62 (50-73)</td>
<td>80 (68-91)</td>
</tr>
<tr>
<td>RV end-systolic volume indexed (mL/m²)</td>
<td>1</td>
<td>91</td>
<td>19 (17-21)</td>
<td>33 (31-34)</td>
<td>46 (44-49)</td>
</tr>
<tr>
<td>3D RV end-diastolic volume indexed (mL/m²)</td>
<td>5</td>
<td>426</td>
<td>40 (28-52)</td>
<td>65 (54-76)</td>
<td>89 (77-101)</td>
</tr>
<tr>
<td>3D RV end-systolic volume indexed (mL/m²)</td>
<td>4</td>
<td>394</td>
<td>12 (1-23)</td>
<td>28 (18-38)</td>
<td>45 (34-56)</td>
</tr>
<tr>
<td>RV subcostal wall thickness (mm) (Figure 5)</td>
<td>4</td>
<td>180</td>
<td>4 (3-4)</td>
<td>5 (4-5)</td>
<td>5 (4-6)</td>
</tr>
<tr>
<td>RVOT PLAX wall thickness (mm) (not shown)</td>
<td>9</td>
<td>302</td>
<td>2 (1-2)</td>
<td>3 (3-4)</td>
<td>5 (4-6)</td>
</tr>
<tr>
<td>RVOT PLAX diameter (mm) (Figure 8)</td>
<td>12</td>
<td>405</td>
<td>18 (15-20)</td>
<td>25 (23-27)</td>
<td>33 (30-35)</td>
</tr>
<tr>
<td>RVOT proximal diameter (mm) (Figure 8, RVOT-Prox)</td>
<td>5</td>
<td>193</td>
<td>21 (18-25)</td>
<td>28 (27-30)</td>
<td>35 (31-39)</td>
</tr>
<tr>
<td>RVOT distal diameter (mm) (Figure 8, RVOT-Distal)</td>
<td>4</td>
<td>159</td>
<td>17 (12-22)</td>
<td>22 (17-26)</td>
<td>27 (22-32)</td>
</tr>
<tr>
<td>RA major dimension (mm) (Figure 3)</td>
<td>8</td>
<td>267</td>
<td>34 (32-36)</td>
<td>44 (43-45)</td>
<td>53 (51-55)</td>
</tr>
<tr>
<td>RA minor dimension (mm) (Figure 3)</td>
<td>16</td>
<td>715</td>
<td>26 (24-29)</td>
<td>35 (33-37)</td>
<td>44 (41-46)</td>
</tr>
<tr>
<td>RA end-systolic area (cm²) (Figure 3)</td>
<td>8</td>
<td>293</td>
<td>10 (8-12)</td>
<td>14 (14-15)</td>
<td>18 (17-20)</td>
</tr>
</tbody>
</table>

Cl, Confidence interval; LRV, lower reference value; PLAX, parasternal long-axis; RA, right atrial; RV, right ventricular; RVD, right ventricular diameter; RVOT, right ventricular outflow tract; 3D, three-dimensional; URV, upper reference value.
RV Territory Coronary Blood Supply
Right ventricle

Normal dimensions
Right ventricle

*Linear dimensions*

- PLAX RVOT : 3.3 cm
- PSAX RVOT : 2.7 cm
- Basal diameter 4.1 cm
- Mid level diameter 3.5 cm
- Longitudinal dimension 8.6 cm
Normal RV < 2/3 LV

RV dilatation:
- Linear dimensions
- Mild: enlarged but RV area < LV area
- Moderate: RV area = LV area
- Severe: RV area > LV area
What structure is this?

- Anterior leaftlet
- Posterior leaflet
- Septal leaflet
- Ostium of CS
- Ostium of IVC
- Eustachian Valve
2D Assessment

**Right atrial size**

- Major-axis (vertical line) < 5.3 cm
- Minor-axis (horizontal line) < 4.4 cm
- RA area < 18 cm²

- New guidelines recommend RA volumes indexed to BSA using apical 4CH view

<table>
<thead>
<tr>
<th></th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA minor axis dimension (cm/m²)</td>
<td>1.9 ± 0.3</td>
<td>1.9 ± 0.3</td>
</tr>
<tr>
<td>RA major axis dimension (cm/m²)</td>
<td>2.5 ± 0.3</td>
<td>2.4 ± 0.3</td>
</tr>
<tr>
<td>2D echocardiographic RA volume (mL/m²)</td>
<td>21 ± 6</td>
<td>25 ± 7</td>
</tr>
</tbody>
</table>

Data are expressed as mean ± SD.
RV function

• Subjective:
  – thickening of the RV wall and inward motion of the RV free wall in multiple views
  – integrate findings from various views

• RV fractional area change (FAC)
• Tricuspid annular descent (TAPSE)
• Tissue Doppler (S’)
• 3D imaging
• Strain Rate Imaging-Mycardial deformation
• Tei index, RIMP Index
RV function

**RV fractional area change**

- RV fractional area change = \( \frac{\text{RVD area - RVS area}}{\text{RVD area}} \)

- Normal: >35%

- Mean 49 =/ 7%

- Validated by (0.69–0.88) 3D echo and MRI estimated RV size
RV function

**Tricuspid annular descent**

- RV ejects blood primarily by shortening of the longitudinal axis

Tricuspid annular plane systolic excursion (TAPSE index) measured in apical 4-chamber view and M-mode cursor through lateral tricuspid annulus

**Normal > 16 mm**
S-wave Tissue Doppler

- Peak systolic velocity of tricuspid annulus by pulsed-wave DTI (cm/sec), obtained from the apical approach, in the view that achieves parallel alignment of Doppler beam with RV free wall longitudinal excursion

- Easy to perform
- Reproducible
- Validated against radionuclide EF
- Established prognostic value
3-D Imaging

- Lower limit of normal 45%
- Mean 58±6%
- Higher in women and older age

Fractional RV volume change by 3D TTE:
RV EF (%) = 100 × (EDV - ESV)/EDV

- Includes RV outflow tract contribution to overall function
- Correlates with RV EF by CMR
- Dependent on adequate image quality
- Load dependency
- Requires offline analysis and experience
- Prognostic value not established
Strain Rate Imaging

\[ \text{Strain} \% = \frac{L_e - L_0}{L_0} \]
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean ± SD</th>
<th>Abnormality threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAPSE (mm)</td>
<td>24 ± 3.5</td>
<td>&lt;17</td>
</tr>
<tr>
<td>Pulsed Doppler S wave (cm/sec)</td>
<td>14.1 ± 2.3</td>
<td>&lt;9.5</td>
</tr>
<tr>
<td>Color Doppler S wave (cm/sec)</td>
<td>9.7 ± 1.85</td>
<td>&lt;6.0</td>
</tr>
<tr>
<td>RV fractional area change (%)</td>
<td>49 ± 7</td>
<td>&lt;35</td>
</tr>
<tr>
<td>RV free wall 2D strain* (%)</td>
<td>−29 ± 4.5</td>
<td>&gt;−20 (&lt;20 in magnitude with the negative sign)</td>
</tr>
<tr>
<td>RV 3D EF (%)</td>
<td>58 ± 6.5</td>
<td>&lt;45</td>
</tr>
</tbody>
</table>
1. Pulmonary artery pressures:
   - PASP
   - PADP
   - mean PAP
   - RAP
2. Pulmonary vascular resistance
3. RVOT TVI
Doppler Assessment

Pulmonary artery systolic pressure

• Peak TR velocity
  – Measured with continuous wave Doppler
  – Reflects RV to RA pressure difference during systole
    \[ \text{RVSP} - \text{RAP} = 4(V_{\text{Tr}})^2 \]
    \[ \text{RVSP} = 4(V_{\text{Tr}})^2 + \text{RAP} \]
  – In the absence of pulmonic stenosis: \[ \text{RVSP} = \text{PASP} \]

• Good correlation between echo and RHC derived PAP
Doppler Assessment

Pitfalls in assessment of PASP

Inaccurate RAP estimate

Presence of pulmonic stenosis (RVSP≠PASP)

Severe TR: Doppler envelope may be cut off because of early equalization of RV and RA pressures > underestimation of PASP

May misrepresent actual pulmonary vascular resistance in various flow and loading conditions
Pulmonary Hypertension

Doppler Assessment

1. Pulmonary artery pressures:
   - PASP
   - PADP
   - mean PAP
   - RAP

2. Pulmonary vascular resistance

3. RVOT TVI
Doppler Assessment

Pulmonary artery (end) diastolic pressure

Pulmonary regurgitant velocity reflects PA to RV pressure difference during diastole

\[
\text{PADP-RVDP} = 4(V_{PI})^2
\]

\[
\text{PADP} = 4(V_{PI})^2 + \text{RAP}
\]
1. Pulmonary artery pressures:
   - PASP
   - PADP
   - mean PAP
   - RAP

2. Pulmonary vascular resistance

3. RVOT TVI
Doppler Assessment

Mean pulmonary artery pressure

- Mean PAP = $4(V_{\text{peak PI}})^2 + RAP$
What is SPAP? Assuming peak and end PI velocities are 3.75 m/s and 3 m/s, RAP 15
Pulmonary Hypertension

Doppler Assessment

1. Pulmonary artery pressures:
   - PASP
   - PADP
   - mean PAP
   - RAP

2. Pulmonary vascular resistance

3. RVOT TVI
Doppler Assessment

Right atrial pressure

- IVC diameter
- IVC collapsibility
- Hepatic venous Doppler
Right atrial pressure

**IVC Diameter and Collapsibility**

- Imaged supine position; subcostal view.
- IVC diameter
  - best measured between 5 and 30 mm from the IVC and RA junction.
- IVC should be captured for 3-5 beats during quiet respiration and during a “sniff” maneuver.
- IVC diameter varies with respiration, with minimal size at end inspiration.
New 2010 Guidelines to Estimate RAP

veins (Figure 4). For simplicity and uniformity of reporting, specific values of RA pressure, rather than ranges, should be used in the determination of SPAP. IVC diameter ≤ 2.1

Table 3 Estimation of RA pressure on the basis of IVC diameter and collapse

<table>
<thead>
<tr>
<th>Variable</th>
<th>Normal (0-5 [3] mm Hg)</th>
<th>Intermediate (5-10 [8] mm Hg)</th>
<th>High (15 mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVC diameter</td>
<td>≤2.1 cm</td>
<td>≤2.1 cm</td>
<td>&gt;2.1 cm</td>
</tr>
<tr>
<td>Collapse with sniff</td>
<td>&gt;50%</td>
<td>&lt;50%</td>
<td>&gt;50%</td>
</tr>
</tbody>
</table>

Secondary indices of elevated RA pressure:
- Restrictive filling
- Tricuspid E/E' > 6
- Diastolic flow predominance in hepatic veins (systolic filling fraction < 55%)
PW Doppler cursor placed in hepatic vein parallel to flow

Waves:
- Systolic forward flow
- Diastolic forward flow pulse
- Atrial systole; reversal of flow

Increase in RAP: pressure gradient between the hepatic veins and the RA decreases, thus lowering the forward systolic flow.
RA Pressure

Exceptions

• Atrial fibrillation
  – Use IVC diameter and collapsibility only.

• Ventilated patients
  – dilated IVC does not correlate with RAP
  – if < 1.2cm, 100% specific for RAP < 10mmHg

• Young patients/athletes
  – IVC may be dilated and systolic wave may be blunted in setting of normal RAP
Pulmonary Hypertension

*Doppler Assessment*

1. Pulmonary artery pressures:
   - PASP
   - PADP
   - mean PAP
   - RAP

2. Pulmonary vascular resistance

3. RVOT TVI
Question

• How do you calculate pulmonary vascular resistance?
  
  A. PASP-CVP/CO
  B. Mean PAP-PCWP/CO
  C. MAP-CVP/CO
  D. PCWP-Mean PAP/CO
Doppler Assessment

*Pulmonary vascular resistance*

- Distinguishing high PAP due to increased pulm flow versus from pulm HTN due to elevated PVR.
- Heart/liver transplant eval.
- CHF
- Congenital heart disease

- \[ \text{PVR} = \left( \frac{\text{Mean Pulmonary Artery Pressure} - \text{PCWP}}{\text{CO}} \right) \]

- PVR (woods units) can be estimated using: \( \frac{\text{TR peak velocity}}{\text{RVOT TVI} \times 10 + 0.16} \)
Doppler Assessment

**RVOT TVI**

- **Normal:**
  - pulm flow contour is symmetric
  - peak velocity occurs in mid-systole (137 +/- 24 msec).

- **Pulmonary HTN:**
  - Pulmonary hypertension: mid-systolic notching of RVOT TVI.
  - Peak velocity occurs earlier in systole (97 +/- 20 msec).
  - Pulmonary artery flow acceleration time (AT): measured using PW in RVOT from onset of flow to peak velocity.
• AT inversely correlates to mean PAP.
• As PAP increases, acceleration time decreases (normal > 120 msec).
• If ACT < 90 msec → PAP is > 60 mmHg
• mPAP = 79 – (0.45 x RVOT AT in msec)
  – If HR < 60 or > 100 then time must be adjusted
Pulmonary Hypertension

2D Assessment

1. RA size
2. RV size
3. Septal flattening
Interventricular septum

Normal motion

- LV maintains a round shape throughout the cardiac cycle
- Reflects higher pressures in the LV compared to the RV in systole and diastole
Which 4 of below are methods recommended by the ASE guidelines to use in combination to assess RV contractile systolic function?

- 1. FAC
- 2. S’
- 3. TAPSE
- 4. SPECKLE TRACKING
- 5. MPI (Tei index)
- 6. RV dP/dt via TR
- 7. 3D volumetrics
Pulmonary Hypertension

Question

Which of the following is not prognostic indicator of survival in PHTN?

A. Presence and size of pericardial effusion
B. Elevated Tei index
C. RA size
D. RVOT TVI AT<62ms
E. TR severity
F. Pulmonary artery pressure
Thank You!