Objectives

• Briefly review right atrial and right ventricular anatomy
• Describe the conventional 2D acoustic windows required for optimal evaluation of the right heart
• Describe the measurements and technique required in routine and directed echocardiography studies
• Identify advantages and disadvantages of each measurement as supported by available literature
• Explain the clinical and prognostic significance of RA/RV assessment
Right Atrium A&P

- Smooth walled myocardium, except for appendage
- Three inlets- SVC, IVC, and coronary sinus
- Visible fetal remnants-
  - Eustachian valve
  - Chiari network
- Normal pressure ranges from 0-5 mmHg
Right Ventricle A&P

- Most anterior chamber
- Crescent shaped
- 3 Sections:
  - Inlet
  - Body
  - Muscular outflow tract
- Moderator band
- Thinner walls compared to LV
- Normal systolic pressure: 15-30 mmHg
In all studies, the sonographer and physician should examine the right heart using multiple acoustic windows, and the report should represent an assessment based on qualitative and quantitative parameters.

The parameters to be performed and reported should include:

1. RV size
2. RA size
3. RV systolic function (at least one of the following: FAC, S’, and TAPSE; with or without RV RIMP)
4. SPAP with estimate of RA pressure on the basis of IVC size and collapse

In many conditions, additional measures such as PAPD and an assessment
Summary of reference limits for recommended measures of right heart structure and function

Values obtained from:

- normal individuals without any histories of heart disease
- excluded those with histories of congenital heart disease

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>Abnormal</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV basal diameter</td>
<td>cm</td>
<td>&gt;4.2</td>
</tr>
<tr>
<td>RV subcostal wall thickness</td>
<td>cm</td>
<td>&gt;0.5</td>
</tr>
<tr>
<td>RVOT PSAX distal diameter</td>
<td>cm</td>
<td>&gt;2.7</td>
</tr>
<tr>
<td>RVOT PLAX proximal diameter</td>
<td>cm</td>
<td>&gt;3.3</td>
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<tr>
<td>RA major dimension</td>
<td>cm</td>
<td>&gt;5.3</td>
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<tr>
<td>RA minor dimension</td>
<td>cm</td>
<td>&gt;4.4</td>
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<tr>
<td>RA end-systolic area</td>
<td>cm²</td>
<td>&gt;18</td>
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<tr>
<td>TAPSE</td>
<td>cm</td>
<td>&lt;1.6</td>
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<tr>
<td>Pulsed Doppler peak velocity</td>
<td>cm/s</td>
<td>&lt;10</td>
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<tr>
<td>Pulsed Doppler MPI</td>
<td></td>
<td>&gt;0.40</td>
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<tr>
<td>Tissue Doppler MPI</td>
<td></td>
<td>&gt;0.55</td>
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<tr>
<td>FAC (%)</td>
<td>%</td>
<td>&lt;35</td>
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<tr>
<td>E/A ratio</td>
<td></td>
<td>&lt;0.8 or &gt;2.1</td>
</tr>
<tr>
<td>E/E' ratio</td>
<td></td>
<td>&gt;6</td>
</tr>
<tr>
<td>Deceleration time (ms)</td>
<td>ms</td>
<td>&lt;120</td>
</tr>
</tbody>
</table>
Acoustic windows and echocardiographic views of the right heart

- *It is important to use all available views*, because each view adds complementary information, permitting a more complete assessment of the different segments of the right heart chambers.
- *Do not use off-axis views for interpretation*
- When there are discrepancies in structure and function between different views, the interpreting physician **must integrate all information** contained within the echocardiographic study *to synthesize* a global assessment of
Parasternal long axis view of RV anterior wall

Measurement of:
• RV enlargement
• RV wall thickness
• RV OT dimension

Caveats:
1. View is highly variable depending on the transducer angulation and the rib interspace from which it was obtained
2. It should not be the sole view to evaluate RVOT size
Parasternal long axis of RVOT and PA

Utility

- Shows anterior RVOT in its long axis view with infundibular segment
- Assessment of PV and PA
- Measurement of PV annular dimension
Parasternal long axis of RV inflow

Assessment of:

- RV anterior and inferior walls
- Anterior and posterior leaflets of TV
- Eustachian valve
- IVC ostium
- TR jet
- CS ostium
Parasternal short axis of basal RV

Utility:

- Assessment of basal anterior RV wall, RVOT, TV, PV and RA
- Measurement of RVOT dimension in diastole
- TR jet
- Assess inter-atrial septum for shunts, especially PFO posterior to the aortic root
Parasternal short axis of bifurcation of PA

Assessment of:
- PV
- MPA
- PA branches
- Proximal RVOT
- Distal RVOT

2D Measurements:
- PV annulus
- PA size
- RV infundibulum

Doppler measurements:
- RVOT velocity, acc. time
- PA max velocity
- PAEDP, MPAP
Parasternal RV short axis at MV level

Utility:

- Assessment of lateral, anterior and inferior walls of basal RV
- Septal flattening - best appreciated
- LVEI calculation
- Crescent shaped RV
- Initial assessment of RV size

Caveat: **Cannot use for assessment of RV systolic function** due to asymmetric nature of RV contraction
Parasternal RV short axis at papillary muscle level

Utility:

- Assessment of lateral, anterior and inferior walls of mid-level RV
- Septal flattening - best appreciated
- LVEI calculation
- Crescent shaped RV
- Initial assessment of RV size

Caveat: **Cannot use for assessment of RV systolic function** due to asymmetric nature of RV contraction
Apical 4 Chamber view

2D Measurements:
- RV: long axis
- RV: minor axis at base and mid levels
- RV: Area, FAC
- RA: area, volume
- RA: major and minor axis
- TASPE

Assessment of RA/RV size, shape and function

Doppler Measurements
- RV inflow
- RV strain
- TR jet Velocity
- S’, RIMP
RV focused Apical 4-Chamber view

Utility

- Recommended alternative to apical 4 chamber to measure RV minor dimension in basal segment of RV
- Useful view for demonstrating RV/RA size, shape and function, with enhanced visualization of the RV free wall
- TR jet parameters
RV modified Apical 4-Chamber view

Utility:
- RV inflow parameters
- TR jet parameters
- ASD and PFO flow

Do not use it quantitatively to assess RA and RV-foreshortened and oblique image angle
RV Apical 5-Chamber view

Utility

- Modified view to visualize the antero-lateral RV wall
- Moderator band-best visualized
- TR jet parameters
Apical coronary sinus view

Utility

• Modified view to visualize posterior lateral RV wall
• Coronary sinus-best view
• TR jet parameters
RV Subcostal 4-chamber view

Utility
- RV wall thickness-best measured in this view
- RA/RV wall inversion/collapse in patients with cardiac tamponade
- ASD and PFO evaluation
- TR jet parameters

Do not use it quantitatively to assess RA and RV-foreshortened and oblique image angle
Subcostal short axis of basal RV

Utility:

- Base of the RV wall including RV inflow, RV outflow, pulmonary valve, pulmonary artery and its branches are well visualized
- RVOT dimensions
- Doppler measurement of the infundibulum, pulmonary valve and pulmonary artery
Ok, let’s measure some stuff…
**RA Dimensions**

- **Maximal long axis distance**: Center of tricuspid annulus to the center of the superior right atrial wall, parallel to the interatrial septum
  
  Abnormal: > 5.3 cm

- **Mid-RA minor distance**: Mid-level of RA free wall through the interatrial septum, perpendicular to the long axis
  
  Abnormal: > 4.4 cm

- **RA area**: Traced at the end of ventricular systole (largest volume) from the lateral aspect of the tricuspid annulus to the septal aspect excluding the area between the leaflets and annulus, following the right atrial endocardium, excluding the IVC and superior vena cava and right atrial appendage
  
  Abnormal: > 18 cm²

Primary transthoracic window: Apical 4 chamber view
Images adequate for RA area estimation should be obtained in patients undergoing evaluation for RV or LV dysfunction.

RA dimensions should be considered in patients with significant RV dysfunction when image quality does not permit for the measurement of RA area.
Determining RA Pressure

- Subcostal view is most useful for imaging the IVC viewed in its long axis.
- Measure at end-expiration and just proximal to the junction of the hepatic veins, approximately 0.5 to 3.0 cm from the ostium of the right atrium.
- To accurately assess IVC collapse, change in diameter of the IVC with a sniff test and also with quiet respiration should be measured, ensuring that the change in diameter does not reflect a translation of the IVC into another plane: Use M-mode.
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>&lt;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%)
RA Pressure: Guideline statements

- For simplicity of reporting, specific values of RA pressure should be used in the determination of SPAP.
- In indeterminate cases, if none of the secondary indices of elevated RA pressure are present, RA pressure may be downgraded to 3 mm Hg.
- If there is minimal IVC collapse with a sniff (<35%) and secondary indices of elevated RA pressure are present, RA pressure may be upgraded to 15mmHg.
- If uncertainty remains, RA pressure may be left at the intermediate value of 8 mm Hg.
- In patients who are unable to adequately perform a sniff, an IVC that collapses < 20% with quiet inspiration suggests elevated RA pressure.
- This method of assigning an RA pressure is preferable to assuming a fixed RA pressure value for all patients.
RA pressure: Misreporting

• Although a distended IVC usually denotes elevated RA pressures, *in patients with otherwise normal exam results, reassessing the IVC size and collapsibility in the left lateral position* may be useful to avoid the potentially erroneous inference of increased RA filling pressure.

• The IVC may also be dilated *in normal young athletes: it may not* reflect elevated RA pressure.
RA pressure: Ventilated patients

- In patients being ventilated using positive pressure, the degree of IVC collapse cannot be used to reliably estimate RA pressure, and RA pressure measured by transduction of a central line should be used if available.
- An IVC diameter ≤ 12 mm in these patients, appears accurate in identifying patients with RA pressures < 10 mm Hg.
- If the IVC is small and collapsed, this suggests hypovolemia.
RA pressure: secondary signs

- Dilated right atrium
- Interatrial septum that bulges into the left atrium throughout the cardiac cycle
RV Wall Thickness

**RVH**
- Infiltrative cardiomyopathy
- Hypertrophic cardiomyopathy
- In patients with significant LV hypertrophy, even in the absence of PH

**RV wall thinning**
- Uhl’s anomaly
- Arrhythmogenic RV cardiomyopathy
- RV infarct
Measurement of end-diastolic right ventricular wall thickness in 2D and M-Mode

• From the subcostal view, align the ultrasound beam perpendicular to the RV free wall.
• Move the focus to the RV wall region and decrease the depth to improve the endocardial border definition.
• Every effort must be made to exclude epicardial fat, erroneously increasing measurement.
• When image quality permits, fundamental imaging should be used to avoid the increased structure thickness seen with harmonic imaging.
Recommendations: RV wall thickness

- Abnormal RV wall thickness *should be reported* in patients suspected of having RV and/or LV dysfunction, using the normal cutoff of 0.5 cm from either PLAX or subcostal windows.
- There are no accepted echocardiographic criteria to define an abnormally thin RV wall.
RV Linear Dimensions: Clinical significance

- The right ventricle dilates in response to chronic volume and/or pressure overload and with RV failure.
- Indexed RV end-diastolic diameter has been identified as a predictor of survival in patients with chronic pulmonary disease.
- RV/LV end-diastolic diameter ratio was shown to be a predictor of adverse clinical events and/or hospital survival in patients with acute pulmonary embolism.
- Correlation of RV linear dimensions with RV end-diastolic volumes appears to worsen with increased preload or afterload.
RV size: Qualitative estimation

Comparison to LV size

• The RV should appear smaller than the LV and usually no more than two thirds the size of the LV in the standard apical 4-C view

• If the RV is larger than the LV in this view, it is likely significantly enlarged
RV size: Qualitative estimation

“Apex-forming” ventricle

- Standard TTE apical 4-C window, the LV is considered the “apex-forming” ventricle
- As the RV enlarges, it may displace the LV and occupy the apex: at least moderately dilated
RV Linear Dimensions: Major limitation of RV imaging

- Lack of fixed reference points to ensure optimization of the right ventricle
- The imager can image the RV through various cut planes, resulting in a normal, medium, or smaller dimension
It is critical to attempt to adjust the apical 4-chamber to acquire the “right ventricle–focused view”

Avoid underestimation

- Rotate the transducer until the maximal plane is obtained

Avoid overestimation

- Ensure that the RV is not foreshortened and that the LVOT is not opened up
- avoid the apical 5-chamber view
Guideline Recommendations: RV linear dimensions

- Patients with echocardiographic evidence of right-sided heart disease or PH should have measurements of RV basal, mid cavity, and longitudinal dimensions on a 4-chamber view.
- In all complete echocardiographic studies, the RV basal measurement should be reported, and the report should state the window from which the measurement was performed (ideally the right ventricle–focused view).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Abnormal</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. RV Basal (RVD1)</td>
<td>&gt; 4.2 cm</td>
</tr>
<tr>
<td>RV Mid (RVD2)</td>
<td>&gt; 3.5 cm</td>
</tr>
<tr>
<td>RV Longitudinal (RVD3)</td>
<td>&gt; 8.6 cm</td>
</tr>
<tr>
<td>B. RVOT PLAX proximal</td>
<td>&gt; 3.3 cm</td>
</tr>
<tr>
<td>C. RVOT PSAX distal</td>
<td>&gt; 2.7 cm</td>
</tr>
<tr>
<td>D. RV Wall Thickness</td>
<td>&gt; 0.5 cm</td>
</tr>
</tbody>
</table>
• Should be measured at end-diastole on the QRS deflection
• Limited normative data are available
• The window for measurement of RVOT size has not been standardized
• Oblique imaging of the RVOT may underestimate or overestimate its size
• The endocardial definition of the anterior wall is often suboptimal
RVOT size: Guideline Recommendations

• Proximal and distal diameters of the RVOT should be measured from the PSAX or PLAX views

• The PSAX distal RVOT diameter, just proximal to the pulmonary annulus, is the most reproducible and should be generally used
RV systolic function assessment

Volumetric assessment
- RV Area and FAC
- 2D Volume and EF Estimation
- 3D Volume Estimation

Non-volumetric assessment
- Global Assessment of RV Systolic Function
- Regional Assessment of RV Systolic Function

Assessment of RV Systolic Function
- RIMP
- TAPSE
- Tissue Doppler methods
- RV dp/dt
FRACTIONAL AREA CHANGE AND VOLUMETRIC ASSESSMENT OF THE RIGHT VENTRICLE

Percentage FAC = \[ \frac{100 \times \text{end-diastolic area-end-systole area}}{\text{end-diastolic area}} \]

- Trace the endocardial border in apical 4-chamber views
- Include the trabeculations, tricuspid leaflets, and chords in the trace
FRACTIONAL AREA CHANGE

- Correlates with RV EF by MRI
- Independent predictor of heart failure, sudden death, stroke, and/or mortality in studies of patients after pulmonary embolism and myocardial infarction
2D FAC is one of the recommended methods of quantitatively estimating RV function, with a lower reference value for normal RV systolic function of 35%
2D RV Volume and EF Estimation

**Area-length method**
- Modified pyramidal or ellipsoidal models
- Underestimates MRI-derived RV volume
- Inferior in comparison with 3D echocardiographic methods

**Disk summation**
- the apical 4-C view
- Exclusion of the RVOT
- Underestimates

**2D RVEF**

Recommendations: 2D derived estimation of RV EF is **not recommended**, because of the heterogeneity of methods and the numerous geometric assumptions.
Global Assessment of RV Systolic Function: RIMP or Tei Index

- Based on the relationship between ejection and non-ejection work of the heart
- The measure remains accurate within a broad range of heart rates
- Feasible in a large majority of subjects both with and without TR
- Reproducible
- Avoids the geometric assumptions and limitations of complex RV geometry
- The pulsed tissue Doppler method allows for measurement of MPI as well as S’, E’, and A’, all from a single image
RIMP: Methods/ Technical aspects

\[ \frac{IVRT + IVCT}{ET} \]

Pulsed Doppler method

Tissue Doppler method

Measurements are taken from different images, and one must therefore attempt to use beats with similar R-R intervals to obtain a more accurate RIMP value.

All time intervals are measured from a single beat by pulsing the tricuspid annulus.
RIMP or *Tei* Index: Recommendations

- The MPI may be used for initial and serial measurements as an estimate of RV function in complement with other quantitative and non-quantitative measures.
- The upper reference limit for the right-sided MPI is 0.40 using the pulsed Doppler method and 0.55 using the pulsed tissue Doppler method.
- It should not be used as the sole quantitative method.
Regional Assessment of RV Systolic Function: TAPSE or Tricuspid Annular Motion (TAM)

Simple and reproducible

Less dependent on optimal image quality

Does not require sophisticated equipment or prolonged image analysis

Zoom on the tricuspid annulus, place cursor across it and measure the amount of longitudinal motion at peak systole.
TAPSE: Recommendations

TAPSE should be used routinely as a simple method of estimating RV function, with a lower reference value for impaired RV systolic function of 16 mm (1.6 cm)
RV systolic function assessment
Tissue Doppler methods: RV S’ or systolic excursion velocity

A simple, reproducible technique with good ability to detect normal versus abnormal RV function
RV S’ or systolic excursion velocity: Technical considerations

An apical 4-chamber window is used with a tissue Doppler mode region of interest highlighting the RV free wall.

The pulsed Doppler sample volume is placed in either the tricuspid annulus or the middle of the basal segment of the RV free wall.

Assessment of the mid and apical RV free wall velocities is discouraged in the routine echocardiographic studies, because there is a lower rate of obtaining adequate signals and greater variability.

Because the interventricular septum does not exclusively reflect RV function, it should not be used alone to assess the RV.
RV S’ Velocity Recommendations

- Interrogation of S’ by pulsed tissue Doppler is a simple and reproducible measure to assess basal RV free wall function and should be used in the assessment of RV function.
- S’ < 10 cm/s should raise the suspicion for abnormal RV function, particularly in a younger adult patient.
RV Diastolic Dysfunction: Recommendations

- Measurement of RV diastolic function should be considered in patients with suspected RV impairment as a marker of early or subtle RV dysfunction or in patients with known RV impairment as a marker of poor prognosis.
- Trans-tricuspid E/A ratio, E/E’ ratio, and RA size have been most validated and are the preferred measures.
- **Grading of RV diastolic dysfunction should be done as follows:**
  1. tricuspid E/A ratio < 0.8 suggests impaired relaxation.
  2. tricuspid E/A ratio of 0.8 to 2.1 with an E/E’ ratio > 6 or diastolic flow predominance in the hepatic veins suggests pseudonormal filling.
  3. tricuspid E/A ratio > 2.1 with a deceleration time < 120 ms suggests restrictive filling (as does late diastolic antegrade flow in the pulmonary artery).
- Further studies are warranted to validate the sensitivity and specificity and the prognostic implications of this classification.
My proposed adoption to normal Protocol:

• In four chamber:
  – Measure basal RV dimension
  – Trace RA area
  – TAPSE
  – Tissue Doppler of TV annulus (measure S’ velocity and E’/A’)

• In subcostal:
  – Measure RV wall thickness
  – IVC diameter from M-mode (inspiration/expiration)
Echocardiographic assessment of the right ventricle has been largely qualitative, primarily because of the difficulty with assessing RV volumes because of its unusual shape.

There are minimal quantitative data overall on RV size and function in normal controls and in disease states.

A gradual shift to more quantitative approaches for the assessment of RV size and function will help standardize assessment of the right ventricle across laboratories and allow clinicians to better incorporate assessment of the right heart into an echocardiographic evaluation.

Improvements in 3D imaging will result in increased use and have the potential to help in the clinical assessment of RV size and function.