Quantitative and Semiquantitative Echocardiography

PERIOPERATIVE POCUS MODULE 6: TRANSESOPHAGEAL ECHOCARDIOGRAPHY ASSESSMENTS
Objectives

- List five semi-quantitative assessments using advanced TEE
- Describe chamber assessment using TEE
- Discuss methods of assessing biventricular function using advanced TEE
- Identify measurements used to assess valve area, gradients and regurgitant volumes
Essential Quantitative Assessments

1. Abnormal chamber sizes (LA, LV, RV)
2. Ejection Fraction
3. Pulmonary Artery Systolic Pressure
4. Mitral valve area and gradient
5. Aortic valve area and gradient
6. Mitral valve regurgitation
7. Aortic valve regurgitation
8. Aorta and aortic valve annulus dimensions
9. E/A ratio (diastology)
10. Tricuspid Annular Plane Systolic Excursion (TAPSE)
Measuring and Imaging Techniques

- Calipers
- Area Tool
- M-Mode
- Color flow mapping with Doppler
  - Use of color box and position
  - Manipulation of Nyquist limit
- Pulse Wave Doppler
- Continuous Wave Doppler
  - Velocity
  - Velocity Time Integral
  - Pressure Half-Time
M-Mode as a TEE Imaging Technique

- Waves are transmitted as a single beam
- Only a limited area is scanned as only tissues which come into this narrow beam are displayed
- Amplitude of returning waves are displayed in shades of brightness
- Valve tissue and myocardium are gray and white, blood is black
- Color doppler may be applied to display velocity and direction of blood flow
The Doppler Principle

- When a sound wave is reflected from a moving object, the frequency of the wave will be different from the emitted wave.
- This frequency is called the Doppler principle.
- The magnitude and direction of the frequency shift are related to the velocity and direction of the moving target.
- In this manner blood flow velocity and direction may be determined (“BART”).
Pulsed Wave (PW) Doppler

- A single crystal sends and receives ultrasound signals then analyzes for frequency shifts
- A cursor is placed on a region on a 2-D image and velocity and direction of blood flow may be determined
- Allows flow direction and velocity in a small region (e.g., atrial appendage) to be measured
- Higher velocities (> 1 m/s) create aliasing and erroneous data (e.g., aortic stenosis)
Continuous Wave (CW) Doppler

Continuous wave doppler uses continuous sampling instead of discrete pulses of ultrasound waves

- Waves are being continuously emitted by multiple transducers
- Region in which flow is measured cannot be precisely located

- Higher velocities are more accurately measured (e.g., aortic stenosis)
TEE may be used to estimate flows, gradients and valve areas.

Direction and velocity of flow may be qualitatively and quantitatively assessed using continuous and pulse wave Doppler.

Intravascular pressures and chamber dimensions may be measured to assess pathology.
Simplified Bernoulli Equation

- If a volume of fluid is moving from higher to lower pressure, then the volume is accelerating in relationship to the pressure difference.

- Used to estimate pressures and gradients across an orifice:
  - Native aortic valve
  - Prosthetic aortic valve
  - Native mitral valve
  - Mitral valve repair/prosthesis

Bernoulli Equation

Conservation of Energy Principle
Relationship between Velocity and Pressure

\[ \Delta P = \frac{1}{2} \rho (v_2^2 - v_1^2) + \int_1^2 \text{dy} \times \text{ds} + R(v) \]

- Convective acceleration
- Flow acceleration
- Viscous friction

Modified Bernoulli’s Equation

\[ \Delta P = 4 (v_2^2 - v_1^2) \]

Simplified Bernoulli’s Equation

\[ \Delta P = 4 v_2^2 \]
Flow towards and away from the transducer is plotted as velocity

- *Pulse* wave Doppler measures flow in a specific sample
- *Continuous wave* Doppler measures all flow along a line

Velocity may be plotted over time (VTI) to estimate flow in a structure or chamber \((SV = CSA \times VTI)\)

In this manner flow in a specific region is estimated
Because liquids are not compressible, flow into an area must equal flow out of an area.

By applying the continuity equation, the flow must be greater in the more narrow area.

Used to calculate areas, specifically valve areas.

Area = A; Velocity = V

\[ A_1 V_1 = A_2 V_2 \]

\[ A_2 = A_1 \frac{V_1}{V_2} \]
Proximal Isovelocity Surface Area (PISA)

- Used to quantify the severity of valvular regurgitation
- PISA assumes that as blood flows towards a regurgitant valve the flow comes together and accelerates
- Color flow Doppler (by adjusting Nyquist limit, $V_n$) may be used to identify the region of increasing velocity and its absolute velocity ($V_o$)
- Flow=Velocity x Area such that regurgitant orifice area (ROA) is calculated by:
  $$\text{ROA}=\frac{2\pi r^2 V_n}{V_o}$$
- Regurgitant Volume=$\text{VTI}_{\text{regurg}} \times (\text{ROA})$
Basic Principles of Semiquantitative Echocardiography

- Basic principles of assessing cardiac chamber size and intracardiac flows are similar to TTE
  - TTE was used for initial assessments
  - Optimal views for TEE are not established
  - Doppler alignment more difficult with TEE
- General anesthesia changes chamber sizes, volumes and pressures
Tricuspid Annular Plane Excursion (TAPSE)
TAPSE = 1.5 cm
Measurement of Cardiac Chamber and Wall Dimensions

- Qualitative assessment of chamber size, function and flow is almost immediate.
- Measurement of chamber sizes reveal ventricular function, valve pathology, cardiac defects and other pathology.
- Chamber wall dimensions reveal pathology as well.
## Normal Chamber Dimensions: ME 4 Chamber

<table>
<thead>
<tr>
<th>Structure</th>
<th>Measurement</th>
<th>Dimension (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Atrium (unreliable)</td>
<td>Diameter (A)</td>
<td>2.7-4.0</td>
</tr>
<tr>
<td>Right Atrium</td>
<td>Minor Axis (B)</td>
<td>2.9-4.5</td>
</tr>
<tr>
<td>Right Ventricle</td>
<td>Basal Diameter (F)</td>
<td>2.0-2.8</td>
</tr>
<tr>
<td></td>
<td>Mid Diameter (G)</td>
<td>2.7-3.3</td>
</tr>
<tr>
<td></td>
<td>Length (H)</td>
<td>7.1-7.9</td>
</tr>
</tbody>
</table>
### Normal Chamber Dimensions: ME 2 Chamber and ME AV LAX

<table>
<thead>
<tr>
<th>Structure</th>
<th>Measurement</th>
<th>Dimension (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Atrium (unreliable)</td>
<td>Diameter (A)</td>
<td>2.7-4.0</td>
</tr>
<tr>
<td>Left Ventricle</td>
<td>Diameter (E)</td>
<td>3.9-5.9</td>
</tr>
<tr>
<td>Aortic Root</td>
<td>Sinus of Valsalva (L)</td>
<td>2.6-4.0</td>
</tr>
</tbody>
</table>

Normal Chamber Dimensions: TG MP SAX

<table>
<thead>
<tr>
<th>Structure</th>
<th>Measurement</th>
<th>Dimension (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Ventricle</td>
<td>Wall Thickness (septal) (C)</td>
<td>0.6-1.0</td>
</tr>
<tr>
<td></td>
<td>Wall Thickness (inferolateral) (D)</td>
<td>0.6-1.0</td>
</tr>
</tbody>
</table>
## Normal Chamber Dimensions

<table>
<thead>
<tr>
<th>Structure</th>
<th>Measurement</th>
<th>Dimension (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Ventricle</td>
<td>Wall Thickness (l)</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Right Ventricular OF</td>
<td>RVOT Diameter (below PV)(J)</td>
<td>2.5-2.9</td>
</tr>
<tr>
<td></td>
<td>RVOT Diameter (above PV)(K)</td>
<td>1.7-2.3</td>
</tr>
<tr>
<td>Pulmonary Artery</td>
<td>Diameter (M)</td>
<td>1.5-2.1</td>
</tr>
<tr>
<td>Structure</td>
<td>Measurement</td>
<td>View</td>
</tr>
<tr>
<td>-------------------------</td>
<td>---------------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td><strong>Chambers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Atrium (unreliable)</td>
<td>Diameter</td>
<td>ME4C or ME2C</td>
</tr>
<tr>
<td>Right Atrium</td>
<td>Minor Axis</td>
<td>ME4C</td>
</tr>
<tr>
<td>Left Ventricle</td>
<td>Wall Thickness (septal)</td>
<td>TGmidSAX</td>
</tr>
<tr>
<td></td>
<td>Wall Thickness (inferolateral)</td>
<td>TGmidSAX</td>
</tr>
<tr>
<td>Left Ventricle</td>
<td>Diameter</td>
<td>ME2C or TG2C</td>
</tr>
<tr>
<td>Right Ventricle</td>
<td>Basal Diameter</td>
<td>ME4C</td>
</tr>
<tr>
<td></td>
<td><strong>Mid Diameter</strong></td>
<td>ME4C</td>
</tr>
<tr>
<td></td>
<td>Length</td>
<td>ME4C</td>
</tr>
<tr>
<td></td>
<td>Wall Thickness</td>
<td>ME4C or RVIFOF</td>
</tr>
<tr>
<td><strong>Tracts/Vessels</strong></td>
<td>Right Ventricular OF</td>
<td>RVOT Diameter (below PV)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RVOT Diameter (above PV)</td>
</tr>
<tr>
<td>Aortic Root</td>
<td><strong>STJ, Proximal Ascending Aorta, Sinus of Valsalva</strong></td>
<td>ME AV LAX</td>
</tr>
<tr>
<td>Pulmonary Artery</td>
<td>Diameter</td>
<td>RVIFOF</td>
</tr>
<tr>
<td>Inferior Vena Cava</td>
<td>Diameter</td>
<td>ME4C (modified)</td>
</tr>
</tbody>
</table>
Left Atrial Dimensions
Left Ventricular Wall Thickness
Septal Wall Thickness
Right Ventricular Dimensions
Use of Doppler to Plot Velocity and Velocity Over Time

- Flow towards and away from the transducer is plotted as velocity
  - Pulse wave Doppler measures flow in a specific sample
  - Continuous wave Doppler measures all flow along a line
- Velocity is used to calculate gradients and regurgitant flow
- Velocity may be plotted over time (VTI) to calculate cardiac output and PASP
Velocity and Velocity Over Time (VTI)
Measurement of Intracardiac Flows

- Doppler allows estimation of intracardiac flows including pulmonary artery and cardiac output
- Flow can be measured over time by measuring VTI and CSA
- VTI is measured with CW doppler
- Cross sectional area is measured by \((\text{diameter}^2 \times 0.785)\)
- \(SV=VTI \times CSA=57\text{ ml}\)
Calculating Pulmonary Artery Systolic Pressure (PASP)

- Doppler of TR jet measures maximum velocity ($V_{\text{max}}$)
- CVP is obtained
- Peak gradient across the valve is calculated using modified Bernoulli equation ($4 \times v_{\text{max}}^2$)
- PASP = CVP + peak gradient
- For CVP 12, max TR velocity 2.3 m/s,
  - PASP = 12 + ($4 \times 2.3^2$) = 33 mmHg
Assessing Diastolic Function

- 38% of the time diastolic assessment is unsuccessful or inaccurate
- E:A ratio is simple yet less than precise
- Tissue Doppler Imaging necessary to make true diagnosis
- Regardless estimate of diastolic dysfunction may be possible
  - Normal: E/A > 0.8, e' > 8 cm/s
  - Grade 1 (Impaired): E/A < 0.8, e' < 8 cm/s
  - Grade 2 (Pseudonormal): E/A > 0.8 with
  - Grade 3 (Restrictive): E/A > 2, e' < 8 cm/s

Diastolic Dysfunction and Diastology

E=45.5
A=58.6
E/A=.78
e'=7.1 cm/s
Assessing Ventricular and Valvular Pathology

- Qualitative assessment of ventricular and valvular pathology may be made with 2-D and color flow mapping.
- Quantitative and semi-quantitative assessments may be made:
  - Volumetric (EF, FAC)
  - Continuous and pulse wave doppler
  - Tissue velocity (Tissue Doppler Imaging)
  - Real-time 3-D TEE
Calculating Ejection Fraction by Fractional Area Change (FAC)

- Ejection Fraction may be calculated by “eyeball EF” or formula
- Ejection Fraction = \( \frac{\text{End-diastolic area} - \text{end-systolic area}}{\text{End-diastolic area}} \)
- EF = (EDA - ESA) / EDA
- EF = (9.46 - 4.08) / 9.46 = 57%
Left Ventricular Function

\[ EF = \frac{EDA - ESA}{EDA} \]

18.1 - 14.2 = 3.9

3.9/18.1 = 21.5%
Left Ventricular Function with M-Mode

7.5 - 6.2 = 1.3
1.3 / 7.5 = 17.3%
Calculating Valve Gradients

- Pressure drop across an orifice may be calculated using the modified Bernoulli equation
  - Gradient=$4(V)^2$
  - “V” is the velocity across the orifice
- Gradient across a valve is calculated and degree of stenosis assessed

Gradient=$4 \times (1.5 \text{ m/s})^2 = 9 \text{ mmHg}$
Calculating Valve Gradients

- Pressure drop across an orifice may be calculated using the modified Bernoulli equation
  - Gradient = $4(V)^2$
  - “V” is the velocity across the orifice

- Gradient across a valve is calculated and degree of stenosis assessed
Mitral Valve Area by Planimetry and PHT
Conventional Aortic Stenosis Assessment
Calculating Valve Area Using the Continuity Equation

- To assess aortic valve area:
  - Cross section LVOT = \( \pi \times \text{radius}^2 = 3.14 \text{ cm} \)
  - VTI LVOT = 15 cm/second
  - VTI Aortic Valve = 60 cm/second

- \( CSA_{AV} = 3.14 \times (15/60) = 0.79 \text{ cm} \)

- Aortic Valve Area = 0.79 cm (severe Aortic Stenosis)
## Aortic Stenosis Severity by TEE

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Velocity (m/s)</td>
<td>1-1.5</td>
<td>&lt;3</td>
<td>3-4</td>
<td>&gt;4.0</td>
</tr>
<tr>
<td>Peak Gradient (mmHg)</td>
<td>&lt;36</td>
<td>36-64</td>
<td>&gt;64</td>
<td></td>
</tr>
<tr>
<td>Mean Gradient (mmHg)</td>
<td>&lt;20</td>
<td>20-40</td>
<td>&gt;40</td>
<td></td>
</tr>
<tr>
<td>AVA (cm²)</td>
<td>2-4</td>
<td>&gt;1.5</td>
<td>1.0-1.5</td>
<td>&lt;1.0</td>
</tr>
</tbody>
</table>
Perioperative Role of TEE with Aortic Stenosis

- Measure aortic valve area using the continuity equation
- Measure gradient across the valve
- Measure annulus size for prosthetic valve
- Measure ascending aorta
- Assess for coexisting valve issues
- Assess biventricular function
- Assess for paravalvular leak and gradient after valve replacement
Doppler Assessment of Aortic Valve
Results of Doppler Assessment of Aortic Valve

- Velocity of flow across aortic valve: 3.8 m/s
- Gradient across valve: 57 mmHg
- LVOT diameter: 1.8 cm
- VTI LVOT: 16.3 cm
- VTI AV: 93.3 cm
- Aortic valve area: 0.44 cm
## Aortic Regurgitation Severity

<table>
<thead>
<tr>
<th>Method</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet/LVOT Width</td>
<td>&lt;25%</td>
<td>25-65%</td>
<td>&gt;65%</td>
</tr>
<tr>
<td>Color Wave Density</td>
<td>Faint</td>
<td>Dense</td>
<td>Dense</td>
</tr>
<tr>
<td>Pressure Half Time (ms)</td>
<td>&gt;500</td>
<td>200-500</td>
<td>&lt;200</td>
</tr>
<tr>
<td>Vena contracta (mm)</td>
<td>&lt;3</td>
<td>3-6</td>
<td>&gt;6</td>
</tr>
<tr>
<td>Regurgitant orifice area (cm²)</td>
<td>&lt;0.1</td>
<td>0.1-0.3</td>
<td>&gt;0.3</td>
</tr>
</tbody>
</table>
Aortic Regurgitation Severity

PHT < 500 ms
Aortic Regurgitation
Severity
LVOT Width 50%
Aortic Regurgitation Severity
Vena Contracta
Utility of TEE for Aorta Surgery

- Chamber/wall/aorta dimensions
  - LV/RV/LA
  - LVOT
  - AV Annulus
  - ST Junction
  - Ascending aorta

- Guidance for cannulation

- Assessment for air

- Assessment after repair or replacement
  - Paravalvular leak
  - Gradient across the valve
# Mitral Regurgitation Severity

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mild (1-2+)</th>
<th>Moderate (2-3+)</th>
<th>Severe (3-4+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet area (% of LA area, cm²)</td>
<td>20%; &lt;4</td>
<td>20-40%; 4-8</td>
<td>&gt;40%; &gt;8</td>
</tr>
<tr>
<td>Vena contracta (cm)</td>
<td>&lt;0.3</td>
<td>0.3-0.6</td>
<td>&gt;0.6</td>
</tr>
<tr>
<td>Pulmonary venous S wave</td>
<td>S&gt;D</td>
<td>Blunting</td>
<td>Reversal</td>
</tr>
<tr>
<td>Regurgitant fraction (%)</td>
<td>&lt;25</td>
<td>25-55</td>
<td>&gt;55</td>
</tr>
<tr>
<td>Regurgitant Orifice Area (cm²)</td>
<td>&lt;0.2</td>
<td>0.2-0.4</td>
<td>&gt;0.4</td>
</tr>
</tbody>
</table>
Mitral Regurgitation Severity
Vena Contracta (Mild)
Mitral Regurgitation Severity
Vena Contracta (Severe)
Mitral Regurgitation Severity
(Pulmonary Venous S Wave)

Normal

Mitral Regurgitation

Pulsed Wave Doppler
Mitral Regurgitation Velocity with CW Doppler
Mitral Valve Repair

- A ring may be sewn around the annulus to improve size or shape
- Leaflets may be better approximated by ring, depending on size of annulus
- Flail leaflet may be anchored with stitch or incised and re-sutured
## Mitral Stenosis Severity

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orifice area (cm²)</td>
<td>1.5-2</td>
<td>1.0-1.5</td>
<td>&lt; 1.0</td>
</tr>
<tr>
<td>Mean gradient (mmHg)</td>
<td>&lt;5</td>
<td>5-10</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Pressure Half Time (ms)</td>
<td>&lt;150</td>
<td>150-220</td>
<td>&gt;220</td>
</tr>
</tbody>
</table>
Stenotic Prosthetic Valve
Mitral Valve Assessment

\[ \frac{316}{220} = 0.7 \text{ cm}^2 \text{ vs } 0.9 \text{ cm}^2 \]
TAPSE Using Two Techniques
Role of TEE with Mitral Stenosis

- Assess pulmonary artery pressures
- Assess tricuspid valve function
- Assess biventricular function especially RV
- Assess LV filling
- Assess for other issues such as patent foramen ovale
Mechanical AV Assessment
Advanced TEE may be used as a supplement for line placement, de-airing and cannulation.

Diagnostic use of advanced TEE includes native and prosthetic valve assessment.

Continuous and pulse wave doppler modes have high utility in advanced TEE.