Aortic Regurgitation: Etiology and Echo Quantification

Martin G. Keane, MD, FASE
Professor of Medicine
Lewis Katz School of Medicine
at Temple University
Review Question #1

Possible reasons that this color Doppler evaluation may overestimate AR include:

A. Low color Doppler gain setting
B. Use of too small a color Doppler sector
C. Low Nyquist velocity setting
D. High pulse repetition frequency (PRF)
Review Question #2

Which condition may lead to over-estimation of AR severity by deceleration slope (or P1/2) of diastolic Continuous Wave (CW) Doppler:

A. Advanced restrictive myocardial disease

B. Severe mitral valve stenosis

C. Severe aortic valve stenosis

D. Low Nyquist limit setting
Review Question #3

- A continuous wave Doppler cursor is placed at the junction of the aortic arch and proximal descending aorta, just beyond the left subclavian artery. The following is obtained:
Review Question #3

- The etiology of the diastolic Doppler flow indicated by the arrow is:

A. Stenosis of the left subclavian artery

B. Severe aortic regurgitation

C. Moderate aortic regurgitation

D. Severe coarctation of the aorta
Aortic Regurgitation: Etiology

- **Valve**
  - Congenital (Bicuspid AV, Subaortic Stenosis)
  - Endocarditis
  - Degenerative
  - Traumatic
  - Rheumatic

- **Aortic Root**
  - Dilated aortic root
    - Marfan, Loeys-Dietz, Ehlers Danlos
    - Hypertension
    - Vasculitis
  - Aortic Dissection
“The Aortic valve is the Root”

- Cusps attached to root in “coronet”
- Sinuses and motion of root important for valve opening and competence
Anatomy of Regurgitation: *Leaflet Malcoaptation*

- **Proximal aortic dilatation**
  - Central Regurgitation

- **Leaflet thickening/retraction**
  - Rheumatic, degenerative

- **Leaflet destruction**
  - Endocarditis, Trauma

- **Leaflet prolapse**
  - Aortic dilatation / dissection
Etiology of Regurgitation: *Bicuspid Aortic Valve*

- Most common “congenital” AV abnormality
- Significant premature valve disease
  - Aortic Regurgitation in 40%
  - Aortic Stenosis in 30%
Etiology of Regurgitation: Degenerative / Rheumatic

- **Degenerative Malcoaptation**
  - Calcific deformities of cusps and commissures

- **Rheumatic Malcoaptation**
  - Thickening/retraction of cuspal edges and commissures

Etiology of Regurgitation: 
*Proximal Aortic Dilatation*

- Marfan, Loeys-Dietz, Ehlers-Danlos
- Non-syndromic aneurysms
- Chronic Hypertension
Etiology of Regurgitation: Aortic Dissection

- Retrograde extension past (proximal) ST junction
- Frequently associated with
  - Rupture into pericardial space, coronary dissection
- Flap may prolapse into/through aortic valve
Etiology of Regurgitation:

*Leaflet Prolapse*

- Myxomatous / Congenital Abnormality
- Loss of commissural support
- Partial tear of cusp (trauma)
- **Best seen on PLAX or on TEE 120°**
Etiology of Regurgitation: 
*Leaflet Destruction by Endocarditis*
Pathophysiology:

Acute Aortic Regurgitation

- Sudden, large regurgitant volume
  - ↑ LVEDV → Marked ↑↑ LVEDP
  - Pulmonary Edema

- Decrease forward stroke volume
  - Cardiogenic shock

- Urgent intervention required
  - Nitroprusside/Inotropic agents
  - Surgical Repair
Pathophysiology:
*Chronic Aortic Regurgitation*

- **Primary Volume Overload**
  - Increased Preload (... & Afterload!)

- **Progressive ventricular dilation**
  - Chamber compliance increases
    - Mild intracavitary pressure increase

- **Myocardial hypertrophy**
  - Compensation for increased wall stress
    - Maintains functionality of the ventricle
Chronic Aortic Regurgitation: Hypertrophy Process

La Place’s Law: $T = \frac{(P \times R)}{M}$

Increase in Radius (R) Compensates for Volume Overload

Wall Thickness (M) also Increases, Normalizing Wall Stress (T)

Chronic Aortic Regurgitation:

- Impaired myocardial function
  - Slow increase in functionally abnormal myocytes

- Decreased coronary flow reserve
  - Secondary to hypertrophy

- Patients become symptomatic at different levels of LV dysfunction
Chronic Aortic Regurgitation: Natural History

Chronic Aortic Regurgitation

Indications for Surgery

- **Symptoms**
  - End-systolic LV dimension > 5.0 cm
  - Ejection fraction < 50%
  - Diastolic LV dimension > 6.5 cm

...or rapid progression/deterioration of indices
Quantitation of Aortic Regurgitation: Echocardiographic Approaches

- **Qualitative**

- **Semi-Quantitative**
  - “Guess-timating” Regurgitant Orifice

- **(Somewhat More) Quantitative**
  - Based on volumetric calculations
## Quantitation of Aortic Regurgitation: Echocardiographic Approaches

### Table 4 Qualitative and quantitative parameters useful in grading aortic regurgitation severity

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LA size</td>
<td>Normal*</td>
<td>Normal or dilated</td>
<td>Usually dilated**</td>
</tr>
<tr>
<td>Aortic leaflets</td>
<td>Normal or abnormal</td>
<td>Normal or abnormal</td>
<td>Abnormal/flail, or wide coaptation defect</td>
</tr>
<tr>
<td><strong>Doppler parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jet width in LVOT –Color Flow</td>
<td>Small in central jets</td>
<td>Intermediate</td>
<td>Large in central jets; variable in eccentric jets</td>
</tr>
<tr>
<td>Jet density–CW</td>
<td>Incomplete or faint</td>
<td>Dense</td>
<td>Dense</td>
</tr>
<tr>
<td>Jet deceleration rate –CW (PHT, ms)</td>
<td>Slow &gt; 500</td>
<td>Medium 500-200</td>
<td>Steep &lt; 200</td>
</tr>
<tr>
<td>Diastolic flow reversal in descending aorta –PW</td>
<td>Brief, early diastolic reversal</td>
<td>Intermediate</td>
<td>Prominent holodiastolic reversal</td>
</tr>
<tr>
<td><strong>Quantitative parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VC width, cm</td>
<td>&lt; 0.3</td>
<td>0.3-0.60</td>
<td>&gt; 0.6</td>
</tr>
<tr>
<td>Jet width/LVOT width, %</td>
<td>&lt; 25</td>
<td>25-45</td>
<td>≥ 65</td>
</tr>
<tr>
<td>Jet CSA/LVOT CSA, %</td>
<td>&lt; 5</td>
<td>5-20</td>
<td>≥ 60</td>
</tr>
<tr>
<td>R Vol, ml/beat</td>
<td>&lt; 30</td>
<td>30-44</td>
<td>≥ 60</td>
</tr>
<tr>
<td>RF, %</td>
<td>&lt; 30</td>
<td>30-39</td>
<td>≥ 50</td>
</tr>
<tr>
<td>EROA, cm²</td>
<td>&lt; 0.10</td>
<td>0.10-0.19</td>
<td>≥ 0.30</td>
</tr>
</tbody>
</table>

Semi-Quantitative: *Jet Width vs. LVOT Diameter*

- Parasternal long axis
- TEE longitudinal plane

- <25% = mild
- 25-64% = moderate
- ≥65% = severe

AR / LVOT = 29%
Moderate AR

AR / LVOT = 73%
Severe AR
We’se gots problems:

What we THINK we are measuring

BUT...
What if??

OR...
Worse yet...

??????
Semi-Quantitative: *Jet Width vs. LVOT diam*

<table>
<thead>
<tr>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mild–Moderate</td>
<td>Moderate–Severe</td>
</tr>
<tr>
<td>&lt; 25%</td>
<td>25–45%</td>
<td>46–64%</td>
</tr>
</tbody>
</table>

### Semi-Quantitative: Jet Width vs. LVOT diam

<table>
<thead>
<tr>
<th></th>
<th>Mild–Moderate</th>
<th>Moderate–Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 25%</td>
<td>25–45%</td>
<td>46–64%</td>
</tr>
</tbody>
</table>

**Pitfalls:**
- Measuring too far down in LVOT
- Low Nyquist limits
- Excessive color Doppler gains
- Eccentrically-directed jets
- Eccentric origin of jets
- Variation of flow (width)
- Blood pressure dependent

Semi-Quantitative: *Jet Area vs. Ao Root Area*

<table>
<thead>
<tr>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5%</td>
<td>5–20%</td>
<td>21–59%</td>
</tr>
<tr>
<td>≥ 60%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Semi-Quantitative:
Jet Area vs. Ao Root Area

Mild
Moderate
Severe

<table>
<thead>
<tr>
<th>Mild-Moderate</th>
<th>Moderate-Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5%</td>
<td>5–20%</td>
</tr>
<tr>
<td>21–59%</td>
<td>≥ 60%</td>
</tr>
</tbody>
</table>

Pitfalls:
- Measuring below the valve
- Low Nyquist limits
- Excessive color Doppler gains
- Multiple jets
- Variation of flow (width)
- Blood pressure dependent

Semi-Quantitative: Vena Contracta

<table>
<thead>
<tr>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.3 cm</td>
<td>0.3–0.60 cm</td>
<td>&gt; 0.6 cm</td>
</tr>
</tbody>
</table>

Semi-Quantitative: Vena Contracta

- Mild: < 0.3 cm
- Moderate: 0.3 – 0.60 cm
- Severe: > 0.6 cm

Pitfalls:
- Eccentric origin (non-circular)
- Imprecision of measurement
- Multiple Jets
- Variation of flow (width)
- Blood pressure dependent

Continuous Wave Doppler

**Slope of Diastolic Spectral Envelope**

- Decrease in Ao - LV pressure gradient
  - Fall in velocity during diastole
  - Flat slope = minimal \( \downarrow \) diastolic gradient
    = mild AR

---

![Aortic Valve Regurgitation Graph](chart.png)
Continuous Wave Doppler
Slope of Diastolic Spectral Envelope

- Decrease in Ao - LV pressure gradient
  - Fall in velocity during diastole
  - Flat slope = minimal ↓ diastolic gradient
    = mild AR

<2.0 m/sec² = mild

>3.5 m/sec² = severe
Semi-Quantitative: *Diastolic CW Doppler Slope*

<table>
<thead>
<tr>
<th>AR jet</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deceleration Slope (m/sec²)</td>
<td>&lt; 2</td>
<td>2 – 3.5</td>
<td>&gt; 3.5</td>
</tr>
<tr>
<td>Pressure Half-time (msec)</td>
<td>&gt; 500</td>
<td>500-200</td>
<td>&lt; 200</td>
</tr>
</tbody>
</table>

### Pitfalls:

- Poor (fuzzy) Doppler envelope
- Some severe AR have long $P_{1/2}$
- Low SVR decreases $P_{1/2}$
- Severe MR decreases $P_{1/2}$
- Restrictive filling decreases $P_{1/2}$

<table>
<thead>
<tr>
<th>Deceleration Slope (m/sec$^2$)</th>
<th>&lt; 2</th>
<th>2 – 3.5</th>
<th>&gt; 3.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Half-time (msec)</td>
<td>&gt; 500</td>
<td>500-200</td>
<td>&lt; 200</td>
</tr>
</tbody>
</table>

Don’t let this happen to you!!
## Qualitative Doppler: Desc. Aorta Flow Reversal

<table>
<thead>
<tr>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brief, Early Diastolic</td>
<td>Intermediate, Early-Mid Diastolic</td>
<td>Prominent, Holodiastolic</td>
</tr>
</tbody>
</table>

Quantitative Doppler for AR Volumetric Calculations

- **Regurgitant volume**
  - \( SV_{LVOT} - SV_{RVOT} \)
  - \( \{\frac{\pi}{4} * (LVOT_{diam})^2\} * VTI_{LVOT} \) - \( \{\frac{\pi}{4} * (RVOT_{diam})^2\} * VTI_{RVOT} \)

- **Regurgitant Fraction**
  - \( RF = \frac{\text{Regurgitant Volume}}{SV_{LVOT}} \)

- **Effective Regurgitant Orifice Area**
  - \( EROA = \frac{\text{Regurgitant volume}}{VTI_{AR}} \)
Quantitative Doppler for AR Volumetric Calculations

Benefits:
- Correlates well with CMR volumetrics
- Multiple jets no problem
- Spectral flow better than color Doppler

Pitfalls:
- Use of mitral inflow requires too many assumptions
- Measuring RVOT flow and dimensions difficult
- Presence of AS confounds (LVOT acceleration)
- Inaccurate with >moderate MR or PR/PS
Quantitative Doppler Regurgitant Volume

<table>
<thead>
<tr>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild–Moderate</td>
<td>Moderate–Severe</td>
<td></td>
</tr>
<tr>
<td>&lt; 30 cc</td>
<td>30–44 cc</td>
<td>45–59 cc</td>
</tr>
<tr>
<td></td>
<td>≥ 60 cc</td>
<td></td>
</tr>
</tbody>
</table>

Quantitative Doppler Regurgitant Fraction

<table>
<thead>
<tr>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild–Moderate</td>
<td>Moderate–Severe</td>
<td></td>
</tr>
<tr>
<td>&lt; 30%</td>
<td>30–39%</td>
<td>40–49%</td>
</tr>
</tbody>
</table>

Quantitative Doppler Regurgitant Orifice Area

<table>
<thead>
<tr>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild–Moderate</td>
<td>Moderate–Severe</td>
<td></td>
</tr>
<tr>
<td>&lt; 10 mm²</td>
<td>10–19 mm²</td>
<td>20–29 mm²</td>
</tr>
</tbody>
</table>

Quantitative Doppler for AR

**PISA is Possible (...but unlikely)**

\[
\text{Surface Area}_{\text{alias}} \times \text{Vel}_{\text{alias}} = \text{EROA}_{\text{AR}} \times \text{Vel}_{\text{AR}}
\]

\[
[2\pi \times r_{\text{alias}}^2] \times \text{Vel}_{\text{alias}} = \text{EROA}_{\text{AR}} \times \text{Vel}_{\text{AR}}
\]

**Regurgitant volume =**

\[
\text{EROA} \times \text{VTI}_{\text{AR}}
\]
WHY DO WE CARE ABOUT THIS??

Timing of Surgical Intervention
Appropriate Patient Follow Up
Passing Echo Board Exams
Aortic Regurgitation: Summary

- Progressive, asymptomatic disease
  - Rate of progression varies individually
  - Close clinical and echo follow up essential

- Medical treatment options are limited

- Symptoms indicate need for surgery

- Severity of AR and LV functional indices
  - KEY parameters in asymptomatic patients
# Aortic Regurgitation: Summary

- **An INTEGRATIVE** approach is required

## Specific signs for AR severity

<table>
<thead>
<tr>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Central Jet, width &lt; 25% of LVOT</td>
<td>Signs of AR&gt;mild present but no criteria for severe AR</td>
<td>● Central Jet, width ≥ 65% of LVOT</td>
</tr>
<tr>
<td>● Vena contracta &lt; 0.3 cm</td>
<td></td>
<td>● Vena contracta &gt; 0.6 cm</td>
</tr>
<tr>
<td>● No or brief early diastolic flow reversal in descending aorta</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Supportive signs

<table>
<thead>
<tr>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Pressure half-time &gt; 500 ms</td>
<td>Intermediate values</td>
<td>● Pressure half-time &lt; 200 ms</td>
</tr>
<tr>
<td>● Normal LV size*</td>
<td></td>
<td>● Holodiastolic aortic flow reversal in descending aorta</td>
</tr>
</tbody>
</table>

## Quantitative parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>R Vol, ml/beat</td>
<td>&lt; 30</td>
<td>30-44</td>
<td>≥ 60</td>
</tr>
<tr>
<td>RF, %</td>
<td>&lt; 30</td>
<td>30-39</td>
<td>≥ 50</td>
</tr>
<tr>
<td>EROA, cm²</td>
<td>&lt; 0.10</td>
<td>0.10-0.19</td>
<td>≥ 0.30</td>
</tr>
</tbody>
</table>

---

Review Question #1

Possible reasons that this color Doppler evaluation may overestimate AR include:

A. Low color Doppler gain setting

B. Use of too small a color Doppler sector

C. Low Nyquist velocity setting

D. High pulse repetition frequency (PRF)
Review Question #1
Answer:

Possible reasons that this color Doppler evaluation may overestimate AR include:

A. Low color Doppler gain setting
B. Use of too small a color Doppler sector
C. Low Nyquist velocity setting
D. High pulse repetition frequency (PRF)
Review Question #2

Which condition may lead to over-estimation of AR severity by deceleration slope (or P1/2) of diastolic Continuous Wave (CW) Doppler:

A. Advanced restrictive myocardial disease
B. Severe mitral valve stenosis
C. Severe aortic valve stenosis
D. Low Nyquist limit setting
Review Question #2

Which condition may lead to over-estimation of AR severity by deceleration slope (or P1/2) of diastolic Continuous Wave (CW) Doppler:

A. Advanced restrictive myocardial disease
B. Severe mitral valve stenosis
C. Severe aortic valve stenosis
D. Low Nyquist limit setting
Review Question #3

- A continuous wave Doppler cursor is placed at the junction of the aortic arch and proximal descending aorta, just beyond the left subclavian artery. The following is obtained:
Review Question #3

The etiology of the diastolic Doppler flow indicated by the arrow is:

A. Stenosis of the left subclavian artery
B. Severe aortic regurgitation
C. Moderate aortic regurgitation
D. Severe coarctation of the aorta
Review Question #3

The etiology of the diastolic Doppler flow indicated by the arrow is:

A. Stenosis of the left subclavian artery
B. Severe aortic regurgitation
C. Moderate aortic regurgitation
D. Severe coarctation of the aorta