Echocardiographic Evaluation of Aortic Valve Prosthesis

Amr E Abbas, MD, FACC, FASE, FSCAI, FSVM, RPVI
Co-Director, Echocardiography,
Director, Interventional Cardiology Research,
Beaumont Health System
Associate Professor of Medicine,
OUWB School of Medicine
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Pre Questions (1)

• Regarding Aortic Prosthetic Valves
  – A. A routine echocardiogram is required very two years after AVR
  – B. An elevated gradient with a decreased EOA is always suggestive of valvular stenosis
  – C. Transthoracic echocardiogram alone is always sufficient to diagnose valvular stenosis
  – D. It is more challenging to quantify para-valvular versus valvular aortic regurgitation.
Pre Questions (2)

• Patients with Prosthesis-Patient Mismatch
  – A. Have abnormal prosthetic valve function
  – B. Progressively worsen with time
  – C. Have a small valve compared to the demands of their body and cardiac output
  – D. Have a benign condition
GUIDELINES AND STANDARDS

Recommendations for Evaluation of Prosthetic Valves With Echocardiography and Doppler Ultrasound

A Report From the American Society of Echocardiography’s Guidelines and Standards Committee and the Task Force on Prosthetic Valves, Developed in Conjunction With the American College of Cardiology Cardiovascular Imaging Committee, Cardiac Imaging Committee of the American Heart Association, the European Association of Echocardiography, a registered branch of the European Society of Cardiology, the Japanese Society of Echocardiography and the Canadian Society of Echocardiography, Endorsed by the American College of Cardiology Foundation, American Heart Association, European Association of Echocardiography, a registered branch of the European Society of Cardiology, the Japanese Society of Echocardiography, and Canadian Society of Echocardiography

William A. Zoghbi, MD, FASE, Chair, John B. Chambers, MD,* Jean G. Dumesnil, MD,† Elyse Foster, MD,‡ John S. Gottdiener, MD, FASE, Paul A. Grayburn, MD, Bijoy K. Khandheria, MBBS, FASE, Robert A. Levine, MD, Gerald Ross Marx, MD, FASE, Fletcher A. Miller, Jr., MD, FASE, Satoshi Nakatani, MD, PhD,§ Miguel A. Quiñones, MD, Harry Rakowski, MD, FASE, L. Leonardo Rodriguez, MD, Madhav Swaminathan, MD, FASE, Alan D. Waggoner, MHS, RDCS, Neil J. Weissman, MD, FASE,‖ and Miguel Zabalgoitia, MD, Houston and Dallas, Texas; London, United Kingdom; Quebec City, Quebec, Canada; San Francisco, California; Baltimore, Maryland; Scottsdale, Arizona; Boston, Massachusetts; Rochester, Minnesota; Suita, Japan; Toronto, Ontario, Canada; Cleveland, Ohio; Durham, North Carolina; St Louis, Missouri; Washington, DC; Springfield, Illinois
Topics of Discussion

• Types and Flow Profiles of Prosthetic Valves
• Echocardiographic Evaluation: Key Points
• Challenges for Evaluation
• Prosthetic Valves Evaluation
  – Elevated gradients
  – Regurgitation
  – Endocarditis
  – Thrombosis versus pannus
Types & Flow Profiles of Prosthetic Valves
Mechanical Vs. Bioprosthetic Vs. Autografts
Types & Flow Profiles of Prosthetic Valves
Mechanical Vs. Bioprosthetic Flow

Bioprosthetic Valve

Bi-leaflet Valve

Blood pressure
LVSP

Flow axis

Blood pressure
LVSP

Flow axis

\[ \Delta P_{VC} \]

\[ \Delta P_{NET} \]

\[ \Delta P_{LO} \]

\[ \Delta P_{CO} \]

\[ SAP_{VC} \]

\[ SAP_{LO} \]

\[ SAP_{CO} \]
Localized Pressure Loss and High Gradient in Central Orifice of Bileaflet Mechanical Valve

(Pressure Recovery)

• Fluoroscopy
ECHO EVALUATION
Guidelines

• CLASS I
  – Initial TTE after AVR (2-4 weeks or sooner if concern for follow up and transfer)
  – Repeat TTE for AVR if there is a change in clinical symptoms or signs suggesting dysfunction
  – TEE for AVR if there is a change in clinical symptoms or signs suggesting dysfunction

• CLASS II
  – Annual TTE in bioprosthetic valves after the first 10 years (5 years in prosthetic statement 2008) but not mechanical valves

Nishimura et al 2014
ECHO EVALUATION:
Key Points

• Clinical picture
• Baseline study
• Type and size of valve
• LV chamber
• BP/HR
• Height/weight/BSA
• Exercise echo may be helpful
• Cinefluoroscopy, CT, MRI
ECHO EVALUATION: Key Points

• Opening and Closing of leaflets or occluders
• Abnormal densities (calcium/mass/vegetation)
• Stability versus rocking motion
• May use Modified versus Simplified Bernoulli
  \[ -4V_2^2 - 4V_1^2 \text{ Vs. } 4V_2^2 \]
• Attention to flow states & adequate Doppler signals
Echo Evaluation: Key Points

• Adequate Doppler Signals
  – LVOT obtained away from flow acceleration (0.5 to 1 cm below sewing ring)
  – Multiple planes
  – Off axis view in parasternal view to obtain LVOT diameter
  – Eccentric aortic regurgitant jets may require different angles to Doppler
Evaluation of Prosthetic Valves: Challenges

• Large range in what is considered normal
• Mean Gradients produced depend on size and type of valve.
• For any particular patient... it is difficult to differentiate normal from abnormal, hence the need for comparison to older studies
• Shadowing may interfere with assessment of location and amount of regurgitation
Bioprosthetic Valve Abnormalities

- Elevated Gradients
- Regurgitation
- Endocarditis
- Thrombosis
- Pannus
3D Echocardiography
Echocardiographic Evaluation of Elevated Prosthetic Valve Gradients
Echocardiographic Approach

**Peak Prosthetic Aortic Jet Velocity > 3 m/s**

- **DVI ≥ 0.30**
  - Jet Contour
  - AT (ms) > 100
  - Consider PrAV stenosis with:
    - Sub-valve narrowing
    - Underestimated gradient
    - Improper LVOT velocity

- **DVI 0.25 - 0.29**
  - Normal PrAV
  - EOA Index
  - High Flow
  - PPM

- **DVI < 0.25**
  - Suggests PrAV Stenosis
  - Consider Improper LVOT velocity
  - AT (ms) < 100

*Note: EOA = Effective Orifice Area, PrAV = Prosthetic Aortic Valve, LVOT = Left Ventricular Outflow Tract, PPM = Pacing Mortality Marker.
Parameters Utilized

- Peak prosthetic aortic velocity

Normal < 3 m/sec  Abnormal > 3 m/sec
Parameters Utilized

• Doppler Velocity Index

Doppler Velocity Index = \( \frac{\text{Velocity}_{LVO}}{\text{Velocity}_{jet}} \)
Doppler Velocity Index

Pulsed Doppler
LVO

1.1/2.8 = 0.39
Normal > 0.3

CW Doppler
Prosthetic AV

1.1/2.8 = 0.39
Normal > 0.3

Obstructed

1/5.5 = 0.18
Abnormal < 0.25
Parameters Utilized

- Jet Contour

Triangular

Rounded
Parameters Utilized

• Acceleration Time

90 msec  
Normal < 100 msec

150 msec  
Abnormal > 100 msec
Parameters Utilized

- Acceleration time/ ejection time
- $\text{AT/ET} > 0.4$: Prosthetic valve obstruction
Parameters Utilized

• Effective Orifice Area and iEOA

\[ A_2 (EOA) = \frac{A_1 \times V_1}{V_2} \]

\[ \text{iEOA} = \frac{AVA}{BSA} \]

Normal > 1.2 cm²
Abnormal < 0.8 cm²
Abnormal < 0.6 cm²/m²
Cause of Elevated Gradients Across Aortic Prosthesis

• Errors in Measurement
  – Improper LVOT Velocity
    • Taken too far from flow acceleration
  – Improper AV Velocity (Gradient) Assessment

• Increased Flow
• Pressure Recovery
• Prosthesis patient mismatch
• Prosthesis stenosis
NORMAL PROSTHESIS FUNCTION
Normal

Pulsed Doppler
LVO

1.1 m/s

CW Doppler
Prosthetic AV

AT = 75 ms

MG = 22 mmHg
DVI = 0.4
PROSTHETIC STENOSIS
Obstructed

Pulsed Doppler
LVO

CW Doppler
Prosthetic AV

MG = 80 mmHg
DVI = 0.18
AT = 180 ms
# Doppler Parameters of Prosthetic Aortic Valve Function

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Suggests Stenosis</th>
</tr>
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<tbody>
<tr>
<td><strong>Peak Velocity</strong></td>
<td>&lt; 3 m/s</td>
<td>&gt; 4 m/s</td>
</tr>
<tr>
<td><strong>Mean Gradient</strong></td>
<td>&lt; 20 mmHg</td>
<td>&gt; 35 mmHg</td>
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<tr>
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<td>&gt;= 0.3</td>
<td>&lt; 0.25</td>
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<td>&gt; 1.2 cm²</td>
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<td>&lt; 80 ms</td>
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</table>
Mechanisms of Prosthetic Valve Dysfunction

A: Wear and tear
B: Calcification
C: Pannus
D: Endocarditis
E: Thrombus
CASE PRESENTATIONS
• CASE PRESENTATION (1):
• 81 Y/O with progressive DOE
• PMHx: Rheumatic valve disease, CABG + Mechanical AVR 2003 (19 St Jude Regent Valve)
• TTE: Difficult to visualize mechanical AV
AV VEL=3.2  
DI=0.58/3.2=0.18  
AT=150msec  
Jet Contour: Circular
An approach to prosthetic AV stenosis

Peak Prosthetic Aortic Jet Velocity $> 3$ m/s

- DVI $\geq 0.30$
- DVI $0.25 - 0.29$
- DVI $< 0.25$

Jet Contour

- AT (ms) $> 100$
- AT (ms) $< 100$
- AT (ms) $> 100$
- AT (ms) $< 100$
An approach to prosthetic AV stenosis

- Peak Prosthetic Aortic Jet Velocity > 3 m/s
  - DVI ≥ 0.30
  - DVI 0.25 – 0.29
  - DVI < 0.25

  Jet Contour
  - AT (ms) >100
  - AT (ms) <100
    - DVI >100: Suggests PrAV Stenosis
    - DVI <100: Consider Improper LVOT velocity
### Doppler Parameters of Prosthetic Aortic Valve Function

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<td>3.2</td>
</tr>
<tr>
<td><strong>Mean Gradient</strong></td>
<td>&lt; 20 mmhg</td>
<td>24</td>
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What is your diagnosis?

- A) Normal Prosthetic Valve Function
- B) Prosthesis – Patient Mismatch
- C) High Flow State
- D) **Prosthetic Valve Stenosis**
- E) Errors of Measurement: Improper LVOT Velocity
Additional Studies Needed?
TEE
Helpful with high gradients and normal motion by Fluoro
• CASE PRESENTATION (2):
• 67 Y/O F Hx AVR (Bi-Leaflet Mechanical Valve 1998)
• On Coumadin, difficulty maintaining therapeutic INR
• Progressive DOE 6 mos
AV VEL = 3.6
DVI = 1.19 / 3.60
DVI = 0.33

Acceleration Time 0.11 sec
An approach to prosthetic AV stenosis

Peak Prosthetic Aortic Jet Velocity $> 3$ m/s

- **DVI $\geq 0.30$**
  - Jet Contour
    - AT (ms) $> 100$

- **DVI 0.25 – 0.29**
  - AT (ms) $< 100$

- **DVI $< 0.25$**
  - AT (ms) $> 100$
  - AT (ms) $< 100$
An approach to prosthetic AV stenosis

Peak Prosthetic Aortic Jet Velocity > 3 m/s

- DVI ≥ 0.30
- DVI 0.25 – 0.29
- DVI < 0.25

Jet Contour

- AT (ms)
  - >100
  - <100

Consider PrAV stenosis with
- Sub-valve narrowing
- Underestimated gradient
- Improper LVOT velocity

*
Original LVOT Velocity Taken Too Close to the AV Prosthesis (*region of sub-valvular acceleration*)
DVI = Velocity LVO / AV Jet
DVI = 0.82 / 3.60
DVI = 0.22

Original LVOT Velocity
Taken Too Close to the AV Prosthesis
An approach to prosthetic AV stenosis

- **Peak Prosthetic Aortic Jet Velocity > 3 m/s**
  - **DVI ≥ 0.30**
    - **Jet Contour**
      - AT (ms) > 100
        - Consider PrAV stenosis with
          - Sub-valve narrowing
          - Underestimated gradient
          - Improper LVOT velocity
    - **AT (ms) < 100**
      - Normal PrAV
      - **EOA Index**
        - High Flow
        - PPM
  - **DVI 0.25 – 0.29**
    - Suggests PrAV Stenosis
  - **DVI < 0.25**
    - Consider Improper LVOT velocity
An approach to prosthetic AV stenosis

Peak Prosthetic Aortic Jet Velocity > 3 m/s

- DVI \( \geq 0.30 
  - DVI 0.25 – 0.29
  - DVI < 0.25

Jet Contour

AT (ms)

- >100
  - Consider PrAV stenosis with
    - Sub-valve narrowing
    - Underestimated gradient
    - Improper LVOT velocity*
  - Normal PrAV
  - Suggestions PrAV Stenosis\
  - Consider Improper LVOT velocity**

EOA Index

- High Flow
- PPM
Surgical Findings

Well seated valve with a large amount of tissue ingrowth beneath the valve resulting in a frozen leaflet
An approach to prosthetic AV stenosis

Peak Prosthetic Aortic Jet Velocity > 3 m/s

- DVI ≥ 0.30
- DVI 0.25 – 0.29
- DVI < 0.25

Jet Contour

AT (ms)
- >100
- <100

- >100

Suggests PrAV Stenosis

<100
What is your diagnosis?

- A) Patient – Prosthesis Mismatch
- B) Normal Prosthetic Valve Function
- C) High Flow State
- D) Prosthetic Valve Stenosis
- E) Improper LVOT Velocity
What is your diagnosis?

• A) Patient – Prosthesis Mismatch
• B) Normal Prosthetic Valve Function
• C) High Flow State
• D) Prosthetic Valve Stenosis
• E) Improper LVOT Velocity (Prosthetic valve stenosis)
• CASE PRESENTATION (3):
• 66 Y/O F Hx AVR (St Jude Valve Conduit 2002 for AR)
• Progressive DOE
• LVOT VELOCITY = 0.85

• AVA VELOCITY = 3.4

• $DVI = \frac{0.85}{3.4} = 0.25$

• AVA VELOCITY = 3.4 m/s
AT = 0.09 sec
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An approach to prosthetic AV stenosis

**Peak Prosthetic Aortic Jet Velocity > 3 m/s**

- **DVI ≥ 0.30**
- **DVI 0.25 – 0.29** (Highlighted)
- **DVI < 0.25**

**Jet Contour**

- **AT (ms)**
  - >100
  - <100

- **Consider PrAV stenosis with**
  - Sub-valve narrowing
  - Underestimated gradient
  - Improper LVOT velocity

- **EOA Index**
  - High Flow
  - PPM

- **Normal PrAV**
  - Suggests PrAV Stenosis

- **Consider Improper LVOT velocity**
An approach to prosthetic AV stenosis

- **Peak Prosthetic Aortic Jet Velocity > 3 m/s**
  - **DVI ≥ 0.30**
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- **Consider PrAV stenosis with**
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  - Improper LVOT velocity

- **EOA Index**
  - Normal PrAV
  - Suggests PrAV Stenosis
  - Consider Improper LVOT velocity

- **High Flow**
- **PPM**
An approach to prosthetic AV stenosis

Indexed EOA = 0.78

PPM occurs when:
- iEOA < 0.85
- Severe if iEOA < 0.65
An approach to prosthetic AV stenosis

Prosthetic Aortic Jet Velocity > 3 m/s

- DVI 0.25 – 0.29
- DVI < 0.25

<100

- Normal PrAV
- EOA Index
  - High Flow
  - PPM

>100

Suggests PrAV Stenosis

<100

Consider Improper LVOT velocity
What is your diagnosis?

- A) **Prosthesis – Patient Mismatch**
- B) Normal Prosthetic Valve Function
- C) High Flow State
- D) Prosthetic Valve Stenosis
- E) Improper LVOT Velocity (Prosthetic valve stenosis)
Patient Prosthesis Mismatch

- **AVA velocity**: 4.6
- **DVI**: $1.14/4.6 = 0.25$, $AVA = 0.4 \text{ cm}^2$
- **Acceleration Time**: 60 msec
Patient Prosthesis Mismatch
Patient Prosthesis Mismatch

• \( \Delta P = \frac{Q^2}{(K \times EOA^2)} \)

• \( Q = \) Flow, \( K = \) Constant

• For gradients to remain low, EOA has to accommodate and be proportionate to flow

• At rest, \( Q \) is determined by BSA

• In patients with large BSA and increased flow, a “too small of a valve” with a small EOA will produce a high gradient
Echocardiographic Evaluation of Prosthetic Valve Regurgitation
Types of Regurgitation

- Regurgitation may be
  - Physiological
  - Pathological
- Physiological regurgitation
  - Closing volume (blood displacement by occluder motion)
  - At the hinges of occluder
Types of Regurgitation

• Pathological
  – Central
    • Mostly with bioprosthetic
    • Technical or infection related
  – Paravalvular
    • Either type, usually the site with mechanical
    • Mild is common after surgery (5-20%) and likely insignificant in the absence of infection
    • Usually after calcium debridement, redo, older patients
    • Hemolytic anemia
    • TAVR
Central Aortic Regurgitation
Central Aortic Regurgitation
Central Aortic Regurgitation
Paravalvular Aortic Regurgitation
Paravalvular Aortic Regurgitation
Assessment of Prosthetic Aortic Valve Regurgitation: TTE

• Challenging due to
  – Shadowing
  – Eccentric Jet
  – Difficult to quantify paravalvular leak

• Width of vena contracta may be difficult to measure

• Off axis views may be required
Assessment of Prosthetic Aortic Valve Regurgitation

- Jet diameter/LVO diameter < 25% in PS views
- Pressure Half Time < 200 ms
- Holodiastolic flow reversal in Descending aorta
- Neck in the short axis view
  - < 10% of sewing ring is mild
  - 10-20% moderate
  - > 20% severe
  - > 40% rocking motion
Assessment of Prosthetic Aortic Valve Regurgitation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valve structure and motion</td>
<td>Usually normal</td>
<td>Abnormal†</td>
<td>Abnormal†</td>
</tr>
<tr>
<td>Structural parameters</td>
<td>Normal‡</td>
<td>Normal or mildly dilated‡</td>
<td>Dilated‡</td>
</tr>
<tr>
<td>Doppler parameters (qualitative or semiquantitative)</td>
<td>Narrow (≤25%)</td>
<td>Intermediate (26%-64%)</td>
<td>Large (≥65%)</td>
</tr>
<tr>
<td>Jet width in central jets (% LVO diameter): color*</td>
<td>Incomplete or faint</td>
<td>Dense</td>
<td>Dense</td>
</tr>
<tr>
<td>Jet density: CW Doppler</td>
<td>Slow (&gt;500)</td>
<td>Variable (200-500)</td>
<td>Steep (&lt;200)</td>
</tr>
<tr>
<td>Jet deceleration rate (PHT, ms): CW Doppler§</td>
<td>Slightly increased</td>
<td>Intermediate</td>
<td>Greatly increased</td>
</tr>
<tr>
<td>LVO flow vs pulmonary flow: PW Doppler</td>
<td>Absent or brief early diastolic</td>
<td>Intermediate</td>
<td>Prominent, holodiastolic</td>
</tr>
<tr>
<td>Diastolic flow reversal in the descending aorta: PW Doppler</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doppler parameters (quantitative)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regurgitant volume (mL/beat)</td>
<td>&lt;30</td>
<td>30-59</td>
<td>&gt;60</td>
</tr>
<tr>
<td>Regurgitant fraction (%)</td>
<td>&lt;30</td>
<td>30-50</td>
<td>&gt;50</td>
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Assessment of Prosthetic Aortic Valve Regurgitation

NORMAL

75 mL

75 mL
Assessment of Prosthetic Aortic Valve Regurgitation

R Volume = 120\text{ mL} - 70\text{ mL} = 50\text{ mL}

R Fraction = \frac{50}{120} = 42\%

AORTIC REGURGITATION
Assessment of Prosthetic Aortic Valve Regurgitation: TEE

• Identifies:
  – Location,
  – Mechanism,
  – AR width to LVOT width,
  – Posterior jets may be identified
• LVOT obscured by accompanied MV prosthesis
• 3D: value? Especially for transcatheter repair
3D in Paravalvular Leak Repair
Echocardiographic Evaluation of Prosthetic Valve Endocarditis
Endocarditis

- Incidence < 1% and has declined with perioperative antibiotics
- Form in valve ring and extend to and spread to stent, occluder, or leaflet
- Irregular and independently mobile
- Can not adequately differentiate between vegetations, thrombus, pledgets, sutures, etc
Endocarditis

• TEE has better sensitivity and specificity for
  – Vegetations
  – Abscess in the posterior but not anterior location
• Combined TEE and TTE have a NPV of 95%
• If clinical suspicion high and studies negative, repeat studies in 7-10 days
Parasternal Long
Color

Lossy compression - not intended for diagnosis
TEE Short
TEE Long

![Ultrasound Image](image-url)

- **FR 22Hz**
- **11cm**
- **2D**: 74%
- **C 50**: P Off
- **Gen**: C 50
- **CF**: 59%
- **4.4MHz**: WF High
- **Med**

**PAT T: 37.0°C**
**TEE T: 39.9°C**
**66 bpm**
Doppler
Pathology
Echocardiographic Evaluation of Prosthetic Valve Thrombosis/Pannus
## Thrombus versus Pannus

<table>
<thead>
<tr>
<th>Thrombus</th>
<th>Pannus</th>
</tr>
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<tbody>
<tr>
<td>• Larger</td>
<td>• Small</td>
</tr>
<tr>
<td>• Soft density similar to myocardium</td>
<td>• Dense, 30% may not be visualized</td>
</tr>
<tr>
<td>• More likely to encounter abnormal valve motion</td>
<td>• Longer duration</td>
</tr>
<tr>
<td>• Short duration of symptom</td>
<td>• More common in aortic</td>
</tr>
<tr>
<td>• Poor anticoagulation</td>
<td></td>
</tr>
<tr>
<td>• Size &lt; 0.85 cm² less likely to embolize</td>
<td></td>
</tr>
<tr>
<td>• More with mechanical</td>
<td></td>
</tr>
</tbody>
</table>
Pannus

TEE
Pre Questions (1)

• Regarding Aortic Prosthetic Valves
  – A. A routine echocardiogram is required very two years after AVR
  – B. An elevated gradient with a decreased EOA is always suggestive of valvular stenosis
  – C. Transthoracic echocardiogram alone is always sufficient to diagnose valvular stenosis
  – D. It is more challenging to quantify para-valvular versus valvular aortic regurgitation.
Answer (1)

- D. It is more challenging to quantify para-valvular versus valvular aortic regurgitation.
Pre Questions (2)

• Patients with Prosthesis-Patient Mismatch
  – A. Have abnormal prosthetic valve function
  – B. Progressively worsen with time
  – C. Have a small valve compared to the demands of their body and cardiac output
  – D. Have a benign condition
Answer (2)

C. Have a small valve compared to the demands of their body and cardiac output
Conclusions

• Elevated gradients across prosthetic aortic valves may be due to other factors besides stenosis

• Regurgitation may be physiological or pathological and may be valvular or paravalvular

• Endocarditis, pannus, and thrombosis may be difficult to distinguish based solely on echocardiographic findings
“Please Let Them do Well on the Boards” Zane Abbas