A Practical Approach to Prosthetic Valves

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Disclosures

- None
1. **Know the Product**
   - Design type & size
   - Flow characteristics
   - Age of valve

2. **Know the Look**
   - Structural appearance
   - Mobility & seating
   - Artifacts

3. **Know the Flow**
   - Maximum & mean gradients
   - Effective orifice area (EOA)
   - Normal regurgitation

4. **Know the Problems**
   - Patient-prosthesis mismatch
   - Obstruction/stenosis
   - Abnormal regurgitation
Each valve differs in its design & flow characteristics

Valve Design
Bileaflet Mechanical Valves

<table>
<thead>
<tr>
<th>Valve</th>
<th>Opening angle</th>
<th>Closing angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>CarboMedics</td>
<td>78°, 78°</td>
<td>25°, 25°</td>
</tr>
<tr>
<td>ATS Open Pivot</td>
<td>85°, 85°</td>
<td>25°, 25°</td>
</tr>
<tr>
<td>On-X</td>
<td>90°, 90°</td>
<td>40°, 40°</td>
</tr>
</tbody>
</table>
Flow Characteristics
Mechanical Valves – Inflow

**Bileaflet**
- 2 large lateral orifices
- 1 smaller central orifice

**Single disk**
- 1 major orifice
- 1 minor orifice

**Ball-cage**
- Flow diverges around the ball

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Flow Characteristics
Mechanical Valves – Regurgitation

**Bileaflet**

**Single disk** (Björk-Shiley)

**Ball-cage**

From John B Chambers Echo Res Pract 2016;3:R35–R43
Know the Look

Prosthetic valves do not have the same look

Design influences 2D appearance

CE AVR
Stented

CLOB AVR
Stentless

SAPIEN
Transcatheter
2 Know the Look

Design influences 2D appearance

Mosaic Stented

St Jude Bileaflet

Starr-Edwards Ball-cage

Know the Look

Normal or Abnormal?

Normal Björk-Shiley

Abnormal ATS
Know the Look

Check the valve bed & stability of valve

Good: Stable
Bad: ‘Rocking’ ≈ Dehiscence

Know the Look

Artifacts: awareness avoids missing a diagnosis

Acoustic shadow & reverberation artifacts
Decreased resolution in far-field with reduced diagnostic accuracy
Artifacts: awareness avoids over-diagnosis

- Beam path artifact in SE MVR (Normal)
- Microbubbles in St Jude MVR (Normal)
### Appendix A. Normal Doppler Echocardiographic Values for Prosthetic Aortic Valves

<table>
<thead>
<tr>
<th>Valve</th>
<th>Parameter</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak velocity</td>
<td>&lt; 3 m/s</td>
</tr>
<tr>
<td></td>
<td>Mean gradient</td>
<td>&lt; 20 mmHg</td>
</tr>
<tr>
<td></td>
<td>Doppler velocity index (DVI)</td>
<td>≥ 0.30</td>
</tr>
<tr>
<td></td>
<td>Effective orifice area (EOA)</td>
<td>&gt; 1.2 cm²</td>
</tr>
<tr>
<td></td>
<td>Contour of the jet velocity</td>
<td>Triangular, early peaking</td>
</tr>
<tr>
<td></td>
<td>Acceleration time (AT)</td>
<td>&lt; 80 ms</td>
</tr>
<tr>
<td>St. Jude Medical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>28.5± 10.7</td>
<td>17.0± 7.8</td>
</tr>
<tr>
<td>Haem Plus</td>
<td>21.6± 17.0</td>
<td>10.6± 5.1</td>
</tr>
<tr>
<td>Bileaflet</td>
<td>16.8± 7.3</td>
<td>12.1± 4.2</td>
</tr>
<tr>
<td></td>
<td>20.6± 12</td>
<td>11.0± 4.9</td>
</tr>
<tr>
<td>St Jude Medical Regent</td>
<td>15.6± 9.4</td>
<td>8.0± 4.8</td>
</tr>
<tr>
<td>Bileaflet</td>
<td>12.8± 6.8</td>
<td>6.9± 3.5</td>
</tr>
<tr>
<td></td>
<td>11.7± 6.8</td>
<td>5.6± 3.2</td>
</tr>
<tr>
<td></td>
<td>7.9± 5.5</td>
<td>3.5± 1.7</td>
</tr>
<tr>
<td>St Jude Medical Standard</td>
<td>42.0± 10.0</td>
<td>24.5± 5.8</td>
</tr>
<tr>
<td>Bileaflet</td>
<td>25.7± 9.5</td>
<td>15.2± 5.0</td>
</tr>
<tr>
<td></td>
<td>21.8± 7.5</td>
<td>13.4± 5.6</td>
</tr>
<tr>
<td></td>
<td>18.9± 7.3</td>
<td>11.0± 5.3</td>
</tr>
<tr>
<td></td>
<td>13.7± 4.2</td>
<td>8.4± 3.4</td>
</tr>
<tr>
<td></td>
<td>13.5± 5.8</td>
<td>7.0± 1.7</td>
</tr>
<tr>
<td>St Jude Medical</td>
<td>22.6± 14.5</td>
<td>10.7± 7.2</td>
</tr>
<tr>
<td>Stentless</td>
<td>16.2± 9.0</td>
<td>8.2± 4.7</td>
</tr>
<tr>
<td></td>
<td>12.7± 8.2</td>
<td>6.3± 4.1</td>
</tr>
<tr>
<td></td>
<td>10.1± 5.8</td>
<td>5.0± 2.9</td>
</tr>
<tr>
<td></td>
<td>7.7± 4.4</td>
<td>4.1± 2.4</td>
</tr>
</tbody>
</table>

Know the Flow
Baseline study early post-op/post-procedure strongly recommended

23 mm ATS AVR

- Vmax = 2.4 m/s
- mPG = 13 mmHg
- DVI = 0.33
- EOA = 1.5 cm²

31 mm ATS AVR

- mPG = 4 mmHg
- DVI = 1.5
- EOA = 2.8 cm²
- PHT = 95 ms

Know the Potential Problems

<table>
<thead>
<tr>
<th>Path</th>
<th>Thrombosis</th>
<th>Pannus</th>
<th>Structural Degeneration</th>
<th>Endocarditis</th>
<th>PPM</th>
<th>Mal-deployment (TAVR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of dysfunction</td>
<td>Obstruction</td>
<td>Obstruction</td>
<td>Stenosis / Regurgitation</td>
<td>Regurgitation / Shunts / stenosis</td>
<td>Non-structural dysfunction</td>
<td>Regurgitation / Stenosis</td>
</tr>
<tr>
<td>Clinical presentation</td>
<td>Echo CHF Shock</td>
<td>Echo CHF Shock</td>
<td>Echo CHF Shock</td>
<td>Echo CHF Shock Sepsis</td>
<td>Echo CHF</td>
<td>Echo CHF Shock</td>
</tr>
</tbody>
</table>

Courtesy Dr Darryl Burstow, The Prince Charles Hospital
50 yo female, 21 mm St Jude AVR, presents with CCF

- Peak PG 76 mmHg (normal 25.7 ± 9.5 mmHg)
- mPG 46 mmHg (normal 15.2 ± 5.0 mmHg)
- EOA 0.83 cm² (normal 1.4 ± 0.4 cm²)
- IEOA 0.40 cm²/m² (abnormal ≤ 0.85 cm²/m²)
- DVI 0.24 (normal ≥ 0.3)
Question

What is the likely cause for increased gradients in this AVR?

1. Prosthesis–patient mismatch
2. LV flow acceleration
3. True obstruction
4. High flow rate due to significant AR
A Diagnostic Pathway for Elevated AVR Gradients

EOA Normal
DVI Normal (≥ 0.3)

YES

IEOA reduced (≤ 0.85 cm²/m²)

NO

Consider:
• PPM

Consider:
• RPR
• Technical error
• High output
• AR
• Technical error
• LVOT flow acceleration

Abnormal leaflet/disc motion

YES

Consider:
• Obstruction

NO

Consider:
• RPR
• Technical error

Our patient:
EOA 0.83 cm² (normal 1.4±0.4 cm²)
DVI 0.24

Adapted from ‘A Sonographer’s Guide to the Assessment of Heart Disease.’ B. Anderson; 2014 Echotext Pty Ltd
Case #1: Follow-up

There is a St Jude 21mm aortic valve replacement, which is well seated with abnormal occluder motion. The anterior occluder motion is severely restricted. There is a soft echogenic linear mass attached to the aortic surface of the anterior occluder which may represent thrombus or pannus (thrombus more likely but appearances non-diagnostic). Its exact size cannot be accurately measured but appears of moderate size. The peak velocity is 4.1 m/s, (normal 2.5 - 3.2 m/s). The mean gradient is 47.5 mmHg, (normal 13 - 23mmHg). Dimensionless Performance Index is 0.2, (normal 0.33 - 0.41). There is grade 3/4 valvular AR. AV Acceleration time 148ms.

Value of AVR Acceleration Time (AT) for Elevated AVR Gradients

DVI ≥ 0.3

- AT >100ms
- Consider AVR stenosis with:
  - Sub-valve narrowing
  - Underestimated gradient
  - Improper LVOT velocity

DVI 0.29–0.25

- AT <100ms
- Normal AVR:
  - Normal IEOA ≈ High flow
  - Reduced IEOA ≈ PPM

DVI <0.25

- AT >100ms
- Suggests AVR stenosis

- AT <100ms
- Likely normal AVR: Consider improper LVOT velocity

Adapted from Zoghbi WA, et al. J Am Soc Echocardiogr. 2009 Sep;22(9):975-1014
Flow Acceleration Time and Ratio of Acceleration Time to Ejection Time for Prosthetic Aortic Valve Function

Sagit Ben Zekry, MD,* Robert M. Saad, MD,* Mehmet Özkan, MD,† Maie S. Al Shabib, MD,‡ Mauro Pepe, MD,§ Manuela Muratori, MD,§ Jianlong Xu, PhD,∥ Stephen H. Little, MD,* William A. Zoghbi, MD,*
Houston, Texas; Istanbul, Turkey; Riyadh, Saudi Arabia; and Milan, Italy

Cut-off AT = 100 ms for identifying AVR stenosis:
- Sens. 86%
- Spec. 86%
- PPV 66%
- NPV 95%


61 yo male, 31mm ATS MVR, 27mm ATS AVR, SOBOE

PLAX

PSAX

AP4

PLAX CFI

PSAX CFI

AP4 CFI
61 yo male, 31mm ATS MVR, 27mm ATS AVR, SOBOE

- Peak E velocity 2.6 m/s
- mPG 10 mmHg (normal 3.1 ± 0.2 mmHg)
- PHT 54 ms
- EOA 2.1 cm² (normal 2.9 ± 0.2 cm²)
- IEOA 0.83 cm²/m² (abnormal ≤ 1.2 cm²/m²)
- DVI 2.8 (normal ≤ 1.8)

Question

What is the likely cause for increased gradients in this MVR?

1. Technical error
2. Significant MR
3. True obstruction
4. Prosthesis-patient mismatch
Question

What is the likely cause for increased gradients in this MVR?

1. Technical error
2. Significant MR
3. True obstruction
4. Prosthesis-patient mismatch

A Diagnostic Pathway for Elevated MVR Gradients

EOA Normal
DVI Normal (< 2.2)

YES

IEOA reduced (≤ 1.2 cm²/m²)

YES
Consider:
• PPM

NO

PHT prolonged (> 130 ms)

YES
Consider:
• Obstruction

NO
Consider:
• MR
• RPR (rare in MVR)

Adapted from 'A Sonographer's Guide to the Assessment of Heart Disease.' B. Anderson; 2014 Echotext Pty Ltd
Our patient:  
\( \text{EOA} \ 2.1 \text{ cm}^2 \) (normal \( 2.9 \pm 0.2 \text{ cm}^2 \))  
\( \text{DVI} \ 2.8 \)

Adapted from ‘A Sonographer’s Guide to the Assessment of Heart Disease.’ B. Anderson; 2014 Echotext Pty Ltd

Consider:
- Obstruction

PHT prolonged (> 130 ms)

Consider:
- MR
- RPR (rare in MVR)

Value of Mitral Valve Prosthesis (MVP) Ratio (or DVI)

\( \text{DVI} = \frac{\text{EOA}}{\text{MVP}} \)

Case #2: Follow-up

There is a 31 mm ATS mitral valve replacement. The prosthetic occluder discs move normally. E velocity is 2.2 m/s, mean gradient is 8 mmHg (normal 2.5 - 4 mmHg). There is extensive anterolateral sewing ring dehiscence extending at least one-third of the circumference (extending between 30 to 160 degrees in the midesophageal view). The defect measures up to 10 mm in width. There is abnormal rocking of the prosthesis adjacent to this defect consistent with significant dehiscence. There are small, mobile strand-like echodensities in this region, which are likely to represent suture material or fibrin. However, vegetations cannot be excluded and clinical correlation is recommended. There is severe, grade 4/4 paravalvular mitral regurgitation. The effective regurgitant orifice area is 80 mm² and the regurgitant volume is 105 ml.

61 yo male, 31mm ATS MVR, 27mm ATS AVR, SOBOE

- Peak E velocity 2.6 m/s
- mPG 10 mmHg (normal)
- PHT 54 ms
- EOA 2.1 cm² (normal 2.9 ± 0.2 cm²)
- IEOA 0.83 cm²/m² (abnormal ≤ 1.2 cm²/m²)
- DVI 2.8 (normal ≤ 1.8)

EOA is NOT accurate in this case due to MR
Continuity Equation for EOA*

\[
\text{EOA} = \frac{\text{SV}_{\text{LVOT}}}{\text{MVR}_{\text{VTI}}}
\]

\[
\text{EOA} = \frac{\uparrow \text{SV}_{\text{LVOT}}}{\uparrow \text{MVR}_{\text{VTI}}}
\]

* Assumes MVR stroke volume = LVOT stroke volume

Know the Product
- Design type & size
- Flow characteristics
- Age of valve

Know the Look
- Structural appearance
- Mobility & seating
- Artifacts

Know the Flow
- Maximum & mean gradients
- Effective orifice area (EOA)
- Normal regurgitation

Know the Problems
- Patient-prosthesis mismatch
- Obstruction/stenosis
- Abnormal regurgitation
# Extra: Pannus versus thrombus

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Thrombus</th>
<th>Pannus</th>
</tr>
</thead>
</table>
| Clinical   | • shorter (≈ 2 months)  
• Symptom duration before reoperation shorter (< 1 month)  
• Inadequate anticoagulation * | • Time from valve surgery to valve malfunction longer (> 12 months)  
• Symptom duration before reoperation  
• longer (≈ 10 months)  
• Adequate anticoagulation* |
| Echocardiography | • Larger  
• Soft tissue appearance (similar to myocardium)  
• Mobile  
• Extension of mass beyond limits of prosthetic valve ring to adjacent cardiac structures  
• More common in MVR than AVR | • Smaller  
• Echo dense appearance  
• Firmly fixed  
• Annular location (along valvular plane)  
• More common in AVR than MVR |

* Adequate anticoagulation defined as International Normalized Ratio (INR) ≥ 2.5 at the time of diagnosis

Extra: Calculation of the EOA

\[
\text{EOA} = \text{CSA LVOT}^* \times \text{LVOT VTI}
\]

or

\[
\text{AVR VTI} \quad \text{or} \quad \text{MVR VTI}
\]

For MVR, ≤ grade 1/4 AR or MR

* CSA LVOT = LVOT diameter\(^2 \times 0.785\)

Extra: DVI for AVR & MVR

\[
\text{DVI (AVR)} = \frac{V_1}{V_2}
\]

PW Doppler LVOT peak velocity (\(V_1\))

CW Doppler AVR peak velocity (\(V_2\))

Normal ≥ 0.30  Abnormal ≤ 0.25

\[
\text{DVI (MVR)} = \frac{\text{MVR VTI}}{\text{LVOT VTI}}
\]

CW Doppler MVR VTI

PW Doppler LVOT VTI

Normal ≤ 1.8  Abnormal ≥ 2.2