Echocardiographic Evaluation of Mitral Valve Prostheses

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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

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Overview

- Description of the various types of prosthetic heart valves
- Echocardiographic evaluation of normally-functioning prosthetic heart valves
- Evaluation of prosthetic heart valve dysfunction
Prosthetic Heart Valves

• Mechanical valves
• Tissue (biological) valves
  – Human
    • Allografts
    • Autografts
  – Animal (xenografts)
    • Porcine aortic valves
    • Bovine pericardial tissue
    • Stented or stentless
• Annular rings
• Percutaneous valves/clips

Mechanical Heart Valves

• Ball-in-cage
  – Starr Edwards valve
• Single tilting disc
  – Medtronic Hall valve
  – OmniScience valve
  – Bjork-Shiley valve
• Bileaflet tilting disc
  – St. Jude Medical valve
  – Carbomedics valve/Sorin
  – On-X
  – ATS
Ball-in Cage
Starr Edwards Valve

- Durable
- Structure:
  - Circular sewing ring
  - Silastic ball
  - Cage with arches
- High profile
- Flow occurs around the ball
- Higher peak velocities
- Backflow volume of 2-5 mL

Single Tilting Disc Valves

- Structure:
  - Circular sewing ring
  - Circular disc eccentrically attached by metal struts
- Closing angle 110° to 130°
- Opening angle 60° to 80°
- Flow occurs through major and minor orifices
- Backflow volume of 5-9 mL
Bileaflet Tilting Disc Valves

- Structure:
  - 2 semicircular discs attached to rigid valve ring by small hinges
- Closing angle 120° to 130°
- Opening angle 75° to 90°
- 3 orifices
  - Central and 2 lateral orifices
- Backflow volume of 5-10 mL

Stented Heterograft Valves

- Structure:
  - sewing ring with 3 semi-rigid stents or struts and fabric sewing cuff
  - Porcine aortic tissue
  - Bovine pericardium
- Trileaflet
  - Opens to a circular orifice
- Regurgitant volume of about 1 mL
  - 10% exhibit a small degree of regurgitation on color flow imaging
Percutaneous Clip

- Mitra-Clip®
- Percutaneous edge-to-edge technique to reduce MR
- FDA-approved for degenerative MR
Echocardiographic Approach to Assessment of Prosthetic Heart Valves

• Evaluation similar to that of native valves
• Reverberations and shadowing play a significant role
• Fluid dynamics of each specific valve prosthesis influences the Doppler findings

Echocardiographic Approach to Prosthetic Heart Valves—All Valve Types

• Complete 2D/3D imaging
• Determine trans-valvular pressure gradients
• Estimate valve orifice area
• Evaluate severity and location of regurgitation
• Estimate pulmonary artery systolic pressure
• Assess chamber sizes and function
• Evaluate other valves
• Clinical data
  – Size and type of prosthesis
  – HR, BP, BSA
• ALWAYS COMPARE TO BASELINE STUDY!
Echocardiographic Approach to Prosthetic Heart Valves—Caveats

• “Normal” Doppler values based on:
  – Prosthesis size
  – Prosthesis type
• Higher gradients compared to native valves
• Reverberation artifacts/shadowing
• Differential diagnosis of high valve gradients:
  – True stenosis
  – High cardiac output states
  – Significant regurgitation
  – Patient-prosthesis mismatch
  – Pressure recovery
Normal Appearance—Tissue Valves

- Stented valves
  - 3 cusps and struts with echogenic sewing ring
Normal Appearance—Mechanical Valves

Ball in cage

Single tilting disk

Bileaflet Mechanical Prosthesis
Complications of Prosthetic Valves

- **Early**
  - Paravalvular leaks
  - Thrombosis/stuck occluders
  - Low output state
  - LVOT obstruction
  - Infective endocarditis
  - Patient prosthesis mismatch (PPM)

- **Late**
  - Structural valve deterioration
  - Thrombosis/thromboembolism
  - Bleeding
  - Pannus ingrowth
  - Regurgitation
  - Infective endocarditis
  - Patient prosthesis mismatch (PPM)
  - Hemolysis
  - Pseudoaneurysm formation
### Probability of an Event at 15-years

<table>
<thead>
<tr>
<th>Event</th>
<th>Mechanical</th>
<th>Bioprosthesis</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death from any cause</td>
<td>n = 88</td>
<td>n = 93</td>
<td></td>
</tr>
<tr>
<td>Any valve-related complication</td>
<td>81 ± 4%</td>
<td>79 ± 4%</td>
<td>0.30</td>
</tr>
<tr>
<td>Systemic embolism</td>
<td>73 ± 6%</td>
<td>81 ± 5%</td>
<td>0.56</td>
</tr>
<tr>
<td>Bleeding</td>
<td>18 ± 5%</td>
<td>22 ± 5%</td>
<td>0.96</td>
</tr>
<tr>
<td>Endocarditis</td>
<td>53 ± 7%</td>
<td>31 ± 6%</td>
<td>0.01</td>
</tr>
<tr>
<td>Valve thrombosis</td>
<td>11 ± 4%</td>
<td>17 ± 5%</td>
<td>0.37</td>
</tr>
<tr>
<td>Perivalvular regurgitation</td>
<td>17 ± 5%</td>
<td>7 ± 4%</td>
<td>0.05</td>
</tr>
<tr>
<td>Reoperation</td>
<td>25 ± 6%</td>
<td>50 ± 8%</td>
<td>0.15</td>
</tr>
<tr>
<td>Primary valve failure (SVD)</td>
<td>5 ± 4%</td>
<td>44 ± 8%</td>
<td>0.0002</td>
</tr>
</tbody>
</table>


### Outcomes of MVR in Patients 50 to 69 years

<table>
<thead>
<tr>
<th>Outcome at 15 Years</th>
<th>No. (%) [95% CI] by Type of Mitral Valve Replacement</th>
<th>Hazard Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mechanical (n = 664)</td>
<td>Bioprosthesis (n = 664)</td>
</tr>
<tr>
<td>Death</td>
<td>209 (50.5-64.4)</td>
<td>221 (54.8-65.0)</td>
</tr>
<tr>
<td>Actuarial 15-year survival, % (95% CI)</td>
<td>57.5 (50.5-64.4)</td>
<td>59.9 (54.8-65.0)</td>
</tr>
<tr>
<td>Stroke</td>
<td>65 (14.0) [9.5-18.6]</td>
<td>41 (6.8) [4.5-8.8]</td>
</tr>
<tr>
<td>Reoperation</td>
<td>28 (5.0) [3.1-6.9]</td>
<td>47 (11.1) [7.6-14.6]</td>
</tr>
<tr>
<td>Bleeding events</td>
<td>72 (14.9) [11.0-18.7]</td>
<td>49 (9.0) [6.4-11.5]</td>
</tr>
</tbody>
</table>

Chikwe J et al. JAMA 2015;331:1435-1442.
Prosthetic Valve Dysfunction

• Approach to suspected dysfunction
  – TTE/Doppler
  – TEE
    • Atrial side of mitral prosthesis
  – Cine fluoroscopy
    • May provide superior assessment of mechanical valve opening and closing motion
    • No assessment of pressure gradients
  – Cardiac CT
  – PET/CT
  – Stress echocardiography
  – Cardiac catheterization

Structural Valve Deterioration

• Tissue Valves
  – More common
    • Younger patients
    • Altered Ca++ metabolism
    • Valve type
  – Thickening, calcification, perforation, or spontaneous tissue degeneration of leaflets
  – Regurgitation
    • Usually gradual
    • Can be acute and massive
  – Stenosis
  – Combination

Valve Thrombosis

- Incidence
  - 0.3% to 1.3%/yr
- Highest risk
  - Mitral and tricuspid positions
- Inadequate anticoagulation
  - Mechanical valves
- Clinical manifestations
  - Incidental finding
  - Peripheral embolization
  - Stenosis
  - Regurgitation
  - Heart failure
- Gradual or acute symptom onset
- Treatments
  - Anticoagulants
  - Thrombolysis
  - Surgery

Bileaflet MVR
Non-obstructive Thrombosis

Mechanical Prosthesis

Bioprosthesis

BPVT vs. Structural Valve Deterioration

BP valve thrombosis

Structural valve deterioration

Obstructive Thrombosis

Thrombus Area by TEE Predicts Clinical Outcome

Infective Endocarditis

- Risk approximately 0.5%/year
- Early versus late pathogens
- Mechanical valves
  - Usually involves the sewing ring
  - Rare to visualize vegetation on discs
- Tissue valves
  - Vegetations seen both at sewing ring and leaflets
- Complications
  - Heart failure
  - Abscess/fistula formation
  - Regurgitation: paravalvular or valvular
  - Stenosis
  - Embolism
  - Conduction defects
Imaging Evaluation for Suspected Endocarditis

Valve Stenosis/Obstruction

- Tissue valves
  - Thickening, calcification and restricted motion
  - Pannus in-growth
  - Thrombosis
- Mechanical valves
  - Restriction of disc/ball motion
    - Thrombus
    - Pannus in-growth
    - Combination
    - Vegetations
  - Restriction of annular area
    - Pannus in-growth

Valve Stenosis/Obstruction

- Mitral valve parameters
  - Peak E-wave velocity
  - Mean gradient
  - Pressure half-time
  - Effective orifice area
    - Continuity equation area
  - DVI
    - $\frac{\text{VTI}_{\text{prosthesis}}}{\text{VTI}_{\text{LVOT}}}$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak E-wave</td>
<td>1.76 m/sec</td>
</tr>
<tr>
<td>PHT</td>
<td>120 msec</td>
</tr>
<tr>
<td>$\text{VTI}_{\text{pros}}$</td>
<td>45 cm</td>
</tr>
<tr>
<td>$\text{VTI}_{\text{lvot}}$</td>
<td>22 cm</td>
</tr>
<tr>
<td>DVI</td>
<td>2.04</td>
</tr>
</tbody>
</table>
Peak E-wave 2.6 m/sec
PHT 166 msec
VTI_{pros} 99 cm

VTI_{LVOT} 17 cm
DVI = 5.8

Prosthetic Mitral Valve Dysfunction?

\[ n = 134 \]

- \( E < 1.9 \)
  - VTI Ratio \( < 2.2 \)
    - PHT < 130
      - Any Dysf 2%
        - Regurg 2%
          - Obstr 0%
    - Any Dysf 14%
      - Regurg 14%
        - Obstr 0%
  - PHT \( \geq 130 \)
    - Any Dysf 100%
      - Regurg 0%
        - Obstr 100%

- \( E \geq 1.9 \)
  - VTI Ratio \( \geq 2.2 \)
    - PHT < 130
      - Any Dysf 83%
        - Regurg 80%
          - Obstr 3%
    - PHT \( \geq 130 \)
      - Any Dysf 100%
        - Regurg 5%
          - Obstr 95%

**Pannus In-growth**

**Versus Thrombosis**
- Anticoagulation usually adequate
- Greater time from implant to presentation
- More echo-dense
- Aortic position more common

Valve Stenosis/Obstruction

• Differential Diagnosis
  – High cardiac output states
    • Anemia, fever, hypovolemia, thyrotoxicosis
  – Significant regurgitation
  – Patient-prosthesis mismatch
  – Pressure recovery

• Caveats
  – Compare to baseline study
  – Take into account:
    • Size/type of prosthesis
    • Cardiac output
    • Heart rate
  – Be aware of pressure recovery
    • Bileaflet mechanical valves primarily in aortic position

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Table 8  Doppler parameters of prosthetic mitral valve function

<table>
<thead>
<tr>
<th></th>
<th>Normal*</th>
<th>Possible stenosis†</th>
<th>Suggests significant stenosis* ‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak velocity (m/s)†</td>
<td>&lt;1.9</td>
<td>1.9-2.5</td>
<td>≥2.5</td>
</tr>
<tr>
<td>Mean gradient (mm Hg)†</td>
<td>≤5</td>
<td>6-10</td>
<td>&gt;10</td>
</tr>
<tr>
<td>VTI_{PrM} / VTI_{LVO}†</td>
<td>&lt;2.2</td>
<td>2.2-2.5</td>
<td>&gt;2.5</td>
</tr>
<tr>
<td>EOA (cm²)</td>
<td>≥2.0</td>
<td>1-2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>PHT (ms)</td>
<td>&lt;130</td>
<td>130-200</td>
<td>&gt;200</td>
</tr>
</tbody>
</table>

Note: PHT is not a valid measure of EOA

Prosthetic Regurgitation

- Tissue valves
  - Degenerative/calcific changes
  - Infective endocarditis
  - Pannus in-growth
  - Paravalvular
- Mechanical valves
  - Paravalvular
    - Dehiscence
    - Poor seating
    - Infection
  - Incomplete closure
    - Pannus in-growth
    - Thrombosis

Prosthetic Regurgitation
Differentiating “Normal” from Pathological Regurgitation

**Normal**
- Characteristic pattern for each valve type
- Symmetric
- Brief
- Non-turbulent
- Lack of associated features
  - Increased antegrade velocities
  - Effects on chamber size and function (hyperdynamic)
  - Increased PASP

**Pathological**
- Asymmetric
  - May flow along atrial wall
- Greater flow duration
  - Persists well into systole
- Turbulent (mosaic) pattern
- Proximal flow acceleration may be present
- Presence of associated features
Evaluation of Prosthetic Regurgitation

• Similar to native valve evaluation
• Prosthetic shadowing limits evaluation
  – Mitral: TEE superior to evaluate LA aspect
• “Pseudo-regurgitation”

Bileaflet Mechanical Prosthesis
Normal Color Flow Pattern
**Pseudo-regurgitation**


**Immediate Post-operative Paravalvular MR**
Prosthesis-Patient Mismatch

- Effective orifice area (EOA) of the prosthetic valve is less than that of the normal native valve
  - PPM occurs when EOA is smaller than expected for BSA
- High transvalvular gradients in normally functioning valves
- EOA indexed to body surface area (EOAi)
  - Mitral valve:
    - Non-significant >1.2 cm²/m²
    - Moderate >0.9 cm²/m² to ≤1.2 cm²/m²
    - Severe ≤0.9 cm²/m²
- Consequences may include:
  - Exercise intolerance
  - Higher pulmonary artery pressures
  - Heart failure
  - Increased mortality

Table 9 Transthoracic echocardiographic findings suggestive of significant prosthetic MR in mechanical valves with normal pressure half-time

<table>
<thead>
<tr>
<th>Finding</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak mitral velocity ≥1.9 m/s² VTI_max/VTI_val = 2.5&quot;</td>
<td>90%</td>
<td>89%</td>
<td>Also consider high flow, PPM</td>
</tr>
<tr>
<td>Mean gradient &gt; 5 mmHg&quot;</td>
<td>90%</td>
<td>70%</td>
<td>At physiologic heart rates; also consider high flow, PPM</td>
</tr>
<tr>
<td>Maximal TR jet velocity &gt; 3 m/s&quot; VTI_max/VTI_val = 2.5&quot;</td>
<td>80%</td>
<td>71%</td>
<td>Consider residual postoperative pulmonary hypertension or other causes</td>
</tr>
<tr>
<td>LV stroke volume derived by 2D or 3D imaging is &gt;30% higher than systemic stroke volume by Doppler</td>
<td>Moderate sensitivity</td>
<td>Specific</td>
<td>Validation lacking; significant MR is suspected when LV function is normal or hypodynamic and VTI_val is &lt;16 cm²/m²</td>
</tr>
<tr>
<td>Systolic flow convergence seen in the left ventricle toward the prosthesis</td>
<td>Low sensitivity</td>
<td>Specific</td>
<td>Validation lacking; technically challenging to detect readily</td>
</tr>
</tbody>
</table>

*PHT <130 msec

Miscellaneous

Cavitary microbubbles

Double spectral profile

Hahn RT. Cardiol Clin 2013;31:287-309.

Follow-up of Prosthetic Heart Valves

ACC/AHA Guidelines

• Class I
  – Initial TTE is recommended after prosthesis implantation (6 wks to 3 mos) for assessment of valve hemodynamics (LOE: B).
  – Repeat TTE is recommended with a change in clinical symptoms or signs suggesting prosthetic valve dysfunction (LOE: C).
  – TEE is recommended when clinical symptoms or signs suggest prosthetic valve dysfunction (LOE: C).

• Class IIa
  – Annual TTE is reasonable in patients with a bioprosthetic valve after the first 10 years, even in the absence of a change in clinical status (LOE: C).

Thank you for your attention