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

2014 AHA/ACC Guideline for the Management of Patients With Valvular Heart Disease
A Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines

Developed in Collaboration With the American Association for Thoracic Surgery,
American Society of Echocardiography, Society for Cardiovascular Angiography and Interventions,
Society of Cardiovascular Anesthesiologists, and Society of Thoracic Surgeons

Prosthetic Heart Valves

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

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** $120^\circ$ to $130^\circ$
- **Opening angle** $75^\circ$ to $90^\circ$
- **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**
  - 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
- Currently 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
  - Date of implant
  - 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 expected compared to native valves
• Effect of 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
  - Echogenic sewing ring
Normal Appearance: Mechanical Valves

- Ball in cage
- Single tilting disk

Bileaflet Mechanical Prosthesis
3-D Appearance

Bileaflet Mechanical Prosthesis

Bioprosthesis

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
  – Paravalvular regurgitation
  – Infective endocarditis
  – Patient prosthesis mismatch
  – Hemolysis
  – Pseudoaneurysm formation
### 15-year Event Rates

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Mechanical n = 88</th>
<th>Bioprosthesis n = 93</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death from any cause</td>
<td>81 ± 4%</td>
<td>79 ± 4%</td>
<td>0.30</td>
</tr>
<tr>
<td>Any valve-related complication</td>
<td>73 ± 6%</td>
<td>81 ± 5%</td>
<td>0.56</td>
</tr>
<tr>
<td>Systemic embolism</td>
<td>18 ± 5%</td>
<td>22 ± 5%</td>
<td>0.96</td>
</tr>
<tr>
<td><strong>Bleeding</strong></td>
<td>53 ± 7%</td>
<td>31 ± 6%</td>
<td>0.01</td>
</tr>
<tr>
<td>Endocarditis</td>
<td>11 ± 4%</td>
<td>17 ± 5%</td>
<td>0.37</td>
</tr>
<tr>
<td>Valve thrombosis</td>
<td>1 ± 1%</td>
<td>1 ± 1%</td>
<td>0.95</td>
</tr>
<tr>
<td>Paravalvular 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</th>
<th>No. (%) [95% CI] by Type of Mitral Valve Replacement</th>
<th>Hazard Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outcome at 15 Years</strong></td>
<td>Mechanical (n = 664)</td>
<td>Bioprothetic (n = 664)</td>
</tr>
<tr>
<td>Death</td>
<td>209</td>
<td>221</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
  - Echocardiography
    - TTE/Doppler
    - TEE
      - Atrial side of mitral prosthesis
  - Cine fluoroscopy
    - 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

Structural Valve Deterioration


Valve Thrombosis/Thromboembolism

- Incidence
  - 0.3% to 1.3%/yr
- Highest risk
  - Mitral and tricuspid positions
  - Inadequate anticoagulation
- BPVT increasing recognition
- Clinical manifestations
  - Incidental finding
  - Peripheral embolization
  - Stenosis
  - Regurgitation
  - Heart failure/shock
- Symptom onset
  - Gradual or acute
- Treatments
  - Anticoagulation
  - Thrombolysis
  - Surgery

Bileaflet MVR
Non-obstructive Thrombosis

Mechanical Prosthesis

Bioprosthesis

BPVT vs. Structural Valve Deterioration

BP valve thrombosis

Structural valve deterioration

Annual Occurrence of Bioprosthetic Valve Dysfunction

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 at sewing ring and/or leaflets
- Complications
  - Heart failure
  - Abscess/fistula formation
  - Regurgitation: paravalvular or valvular
  - Stenosis
  - Embolism
  - Conduction defects
Imaging Evaluation for Suspected Infective 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
    • $\text{VTI}_{\text{prosthesis}} / \text{VTI}_{\text{LVOT}}$
Prosthetic Mitral Valve Dysfunction?

n = 134

- E < 1.9  
  - VTI Ratio < 2.2  
    - PHT < 130  
      - Any Dysf 2%  
        - Regurg 2%  
        - Obstr 0%
    - PHT ≥ 130  
      - Any Dysf 14%  
        - Regurg 14%  
        - Obstr 0%
- VTI Ratio ≥ 2.2  
  - PHT < 130  
    - Any Dysf 100%  
      - Regurg 0%  
      - Obstr 0%
    - Any Dysf 29%  
      - Regurg 29%  
      - Obstr 3%
    - Any Dysf 83%  
      - Regurg 8%  
      - Obstr 5%
  - PHT ≥ 130  
    - Any Dysf 100%  
      - Regurg 0%  
      - Obstr 95%


Peak E-wave  1.76 m/sec
PHT          120 msec
VTI_{pros}   45 cm

VTI_{ivot}   22 cm
DVI = 2.04
Peak E-wave 2.6 m/sec
PHT 166 msec
$VTI_{\text{pros}}$ 99 cm

$VTI_{\text{LVOT}}$ 17 cm

DVI = 5.8
An Algorithm for Evaluation of Bioprostheses


Pannus In-growth

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>VTILPMV/VTLVO† $^$</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
TTE Findings Suggestive of Significant Prosthetic MR in Mechanical Valve with Normal PHT*

<table>
<thead>
<tr>
<th>Finding</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak mitral velocity (&gt;1.9) m/s*</td>
<td>90%</td>
<td>89%</td>
<td>Also consider high flow, PPM</td>
</tr>
<tr>
<td>(V_{T1,MAX}/V_{T1,VO} \geq 2.5)*</td>
<td>89%</td>
<td>91%</td>
<td>Measurement errors increase in atrial fibrillation due to difficulty in matching cardiac cycles; also consider PPM</td>
</tr>
<tr>
<td>Mean gradient (\leq 5) mmHg*</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*</td>
<td>60%</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;90% 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 hyperdynamic and (V_{T1,VO} &lt; 16) cm³/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


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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 trans-valvular gradients with normal valve function
- 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
### Miscellaneous Findings

- **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