Echocardiographic evaluation of Patients–Prosthesis Mismatch

Seol Sang-Hoon

Inje University College of Medicine, Haeundae Paik Hospital, Busan, Korea
Doppler evaluation of Prosthetic valves

High mean pressure gradient - Prosthetic valve obstruction?

1. Bioprosthetic degeneration
2. Functional: Regurgitation, High cardiac output
3. Prosthetic thrombosis
4. Pannus growth
5. Patient - Prosthesis Mismatch
Table 1  Theoretical comparison of mean transvalvar pressure gradient in five hypothetical patients receiving the same prosthetic valve but having different body surface areas

<table>
<thead>
<tr>
<th>Patient number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body surface area (m²)</td>
<td>1.5</td>
<td>1.75</td>
<td>2.0</td>
<td>2.25</td>
<td>2.5</td>
</tr>
<tr>
<td>Cardiac output (l/min)</td>
<td>4.5</td>
<td>5.25</td>
<td>6.0</td>
<td>6.75</td>
<td>7.5</td>
</tr>
<tr>
<td>Valve EOA (cm²)</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Mean pressure gradient (mm Hg)</td>
<td>13</td>
<td>17</td>
<td>22</td>
<td>28</td>
<td>35</td>
</tr>
</tbody>
</table>

For this simulation, mean pressure gradient was calculated assuming a cardiac index of 3 l/min/m², a heart rate of 65 beats/min, and a systolic ejection time of 300 ms.

EOA, effective orifice area.

Reproduced and modified from Pibarot and Dumesnil⁵ with permission of Remedica Publishing.
Patient–Prosthesis mismatch (PPM) was first introduced in 1978 by Rahimtoola.

“Mismatch can be considered to be present when the effective prosthetic valve area, after insertion into the patient, is less than that of a normal human valve.”

PPM occurs when the effective orifice area of the prosthesis is too small in relation to the patient’s body size, resulting in abnormally high postoperative gradients.

Parameters are used to define PPM

1. Calculate in vivo EOA after operation
2. Use in vivo EOA reference
3. Use GOA (geometric orifice area)
4. Size of prosthesis regardless of type

EOA (effective orifice area) = physiologic parameter derived from hydraulic principles

GOA (geometric orifice area) = anatomic area of the prosthesis at inflow, calculated from the static measurement of the inner diameter of the prosthesis at that level; no relation to hemodynamics and gradients
geometric orifice area (GOA)

The geometric orifice area (GOA) is a measurement deriving from the internal diameter of the prosthesis and measured in vitro by the valve manufacturer.
Comparison of geometric orifice area (GOA) and effective orifice area (EOA) values among different sizes of a commonly implanted bioprosthetic and mechanical valve.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CE-19</th>
<th>SJM-19</th>
<th>CE-21</th>
<th>SJM-21</th>
<th>CE-23</th>
<th>SJM-23</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOA</td>
<td>1.96</td>
<td>1.63</td>
<td>2.9</td>
<td>2.06</td>
<td>3.9</td>
<td>2.55</td>
</tr>
<tr>
<td>EOA</td>
<td>0.9</td>
<td>1.1</td>
<td>1.1</td>
<td>1.5</td>
<td>1.5</td>
<td>2.13</td>
</tr>
</tbody>
</table>

CE: Carpentier-Edwards pericardial valves; SJM: St. Jude Medical Standard mechanical valves.

Generally valve area regardless of type: GOA > EOA
Normal reference values of EOAs* for prosthetic valves (in vivo)

<table>
<thead>
<tr>
<th>Valve type</th>
<th>19</th>
<th>21</th>
<th>23</th>
<th>25</th>
<th>27</th>
<th>29</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stented bioprosthetic valves</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medtronic Mosaic</td>
<td>1.20</td>
<td>1.22</td>
<td>1.38</td>
<td>1.65</td>
<td>1.80</td>
<td>2.00</td>
</tr>
<tr>
<td>Hancock II</td>
<td>NA</td>
<td>1.18</td>
<td>1.33</td>
<td>1.46</td>
<td>1.55</td>
<td>1.60</td>
</tr>
<tr>
<td>Carpentier-Edwards Perimount</td>
<td>1.10</td>
<td>1.30</td>
<td>1.50</td>
<td>1.80</td>
<td>1.80</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Stentless bioprosthetic valves</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medtronic Freestyle</td>
<td>1.15</td>
<td>1.35</td>
<td>1.48</td>
<td>2.00</td>
<td>2.32</td>
<td>NA</td>
</tr>
<tr>
<td>St Jude Medical Toronto SPV</td>
<td>–</td>
<td>1.30</td>
<td>1.50</td>
<td>1.70</td>
<td>2.00</td>
<td>2.50</td>
</tr>
<tr>
<td>Prima Edwards</td>
<td>0.80</td>
<td>1.10</td>
<td>1.50</td>
<td>1.80</td>
<td>2.30</td>
<td>2.80</td>
</tr>
<tr>
<td><strong>Mechanical valves</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medtronic-Hall</td>
<td>1.19</td>
<td>1.34</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>St Jude Medical Standard</td>
<td>1.04</td>
<td>1.38</td>
<td>1.52</td>
<td>2.08</td>
<td>2.65</td>
<td>3.23</td>
</tr>
<tr>
<td>St Jude Medical Regent</td>
<td>1.60</td>
<td>2.00</td>
<td>2.20</td>
<td>2.50</td>
<td>3.60</td>
<td>4.40</td>
</tr>
<tr>
<td>MCRI On-X</td>
<td>1.50</td>
<td>1.70</td>
<td>2.00</td>
<td>2.40</td>
<td>3.20</td>
<td>3.20</td>
</tr>
<tr>
<td>Carbomedics</td>
<td>1.00</td>
<td>1.54</td>
<td>1.63</td>
<td>1.98</td>
<td>2.41</td>
<td>2.63</td>
</tr>
<tr>
<td>Sorin Bicarbon</td>
<td>NA</td>
<td>1.66</td>
<td>1.96</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

*Expressed as mean values available in the literature.
Correlation between postop. mean gradient and parameters calculated at the time of operation

\[ Y = 22.7 - 7.0X \]
\[ \text{SEE} = \pm 7.0 \text{ mm Hg} \]
\[ r = 0.32 \]

\[ Y = -2.21 + 9.55/X^2 \]
\[ \text{SEE} = \pm 5.4 \text{ mm Hg} \]
\[ r = 0.67 \]
The indexed EOA is the only parameter that has been found to consistently correlate with postoperative gradients.
$$EOA_{PrAV} = \frac{SV_{LVO}}{TVI_{PrAV}}$$

Calculate continuity equation when using echocardiography.

**LVOT (left ventricle outflow tract)**
- Para-sternal long axis

**LVOT area (cm²)**

$$LVOT\ area = \left(\frac{d}{2}\right)^2 \times \pi$$

**LVOT velocity and TVI**
- Apical 5 chamber

**Stroke Volume**

$$SV_{LVO} = LVOT\ area \times TVI$$

$$= \left(\frac{d}{2}\right)^2 \times \pi \times TVI$$

**TVI_{PrAV}**

= TVI across the prosthesis using CW Doppler
**PPM has been the indexed EOA**

IEOA = \[ \frac{\text{EOA of the prosthesis}}{\text{Patient’s body surface area (BSA)}} \]

**EOA** (effective orifice area) = physiologic parameter derived from hydraulic principles and corresponding to the actual area occupied by flow as it exit the valve; directly related to hemodynamics and gradients.
Aortic valve

- PPM is considered the indexed EOA (0.8~0.9)
  - Not clinically significant: > 0.85 cm²/m²
  - Moderate: > 0.65 to ≤0.85 cm²/m²
  - Severe: ≤0.65 cm²/m²
Abnormally high transvalvular pressure gradients after aortic valve replacement
- 1266 consecutive patients and define PPM (iEOA : > 0.85, 0.65~0.85, < 0.65)
- Indexed EOA: each type and size of prosthetic valve (reference values)
- Follow-up time: within 30 days after operation
Relative risk ratio for short-term mortality according to valve PPM and preoperative LV EF

- 315 consecutive patients with pure aortic stenosis
- PPM: indexed EOA ≤ 0.80 cm²/m²
- iEOA: each type and size of prosthesis (references values)
- Mean follow-up time: 3.7 ± 1.7 years
- PPM was present in 47% of patients

**Overall Mortality**

**Cardiac Events**

Cardiac events: cardiac death, sudden death, heart failure, syncope, angina

Tasca G. et al. Circulation. 2006;113:570-576
• 388 patients with 19 or 21-mm St Jude Medical prostheses
• PPM: indexed EOA: 0.60, 0.60–0.85, 0.85
• indexed EOA: transthoracic echocardiography within 1 year after AVR (in vivo)
• PPM: severe: 66 pts (17%), moderate: 168 pts (43%), not significant: 154 pts (40%)

The long-term survival rates at 5 and 8 years, respectively, for patients with severe PPM were significantly lower than those for patients with moderate PPM (P= 0.026) or not significant PPM (P= 0.002).
Mitral valve

- Rahimtoola and Murphy were the first (1981) to describe the case of a patient with PPM in the mitral position.


- Normalization of pulmonary artery pressure is a goal of mitral valve replacement since even mild pulmonary hypertension can impair exercise capacity and may increase morbidity and mortality.

- The prosthetic-patient mismatch (PPM) may cause postoperative pulmonary hypertension.
EOA of Mitral valve

1. Calculation by the continuity equation method

   may be better for bioprosthetic valves and single tilting disc mechanical valves
   than bileaflet valves

2. Calculation from pressure half-time method

   is not valid in prosthetic valves, because of its dependence on LV and LA compliance and initial LA pressure.

3. Use MV mean gradient (indirect)
A patient with documented St. Jude prosthetic mitral valve obstruction and previous myocardial infarction
**EOA**<sub>PrMV</sub> = \( \frac{SV_{LVO}}{TVI_{PrMV}} \)

LVOT (left ventricle outflow tract)  
Para-sternal long axis

LVOT area (cm\(^2\)) = \( (\frac{d}{2})^2 \times \pi \)

LVOT velocity and TVI 측정  
Apical 5 chamber  
AV annulus 혈류속도 (pulse Doppler)

Stroke Volume = LVOT area \( \times \) TVI  
= \( (\frac{d}{2})^2 \times \pi \times TVI \)

TVI<sub>PrMV</sub> = TVI across the prosthesis using CW Doppler
Mitral valve

- PPM is considered the indexed EOA (1.2~1.3)
  - Not clinically significant: > 1.2 cm²/m²
  - Moderate: > 0.9 to ≤ 1.2 cm²/m²
  - Severe: ≤ 0.9 cm²/m²
• 56 patients with normally functioning mitral prosthetic valves
  Systolic PA pressure: by Doppler echocardiography

• iEOA: the continuity equation and indexed for BSA

• PA hypertension: systolic PA pre. 40 mm Hg (54%)
  PPM: an indexed EOA < 1.2 cm2/m2 (71%)

• The average systolic PA pressure and prevalence of
  PA hypertension were $34 \pm 8$ mm Hg and 19% in patients
  with no PPM versus $46 \pm 8$ mm Hg and 68% in patients with
  PPM ($p < 0.001$)
Correlation between systolic PA pressure and indexed mitral valve EOA

Persistent PA hypertension is frequent after MVR and strongly associated with the presence of PPM
In the Quebec study of 929 patients who underwent mitral valve replacement, the EOAI was used to define PPM as severe, moderate and nonsignificant - in vivo reference values (0.9, 1.2)

Moderate PPM: 69%; severe PPM was seen in 9%

<table>
<thead>
<tr>
<th>Variables</th>
<th>All Patients (n=182)</th>
<th>Nonsignificant PPM (n=41)</th>
<th>Moderate PPM (n=124)</th>
<th>Severe PPM (n=17)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitral peak gradient, mm Hg</td>
<td>9.7±3.5</td>
<td>8±2.4</td>
<td>9.8±3.3*</td>
<td>13.4±4.6†</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mitral mean gradient, mm Hg</td>
<td>3.5±1.7</td>
<td>2.6±1.0</td>
<td>3.9±1.3*</td>
<td>6.0±2.6†</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Systolic PA pressure, mm Hg</td>
<td>41±9</td>
<td>38±9</td>
<td>41±8*</td>
<td>49±12†</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Measured EOa, cm²</td>
<td>1.9±0.36</td>
<td>2.01±0.3</td>
<td>1.90±0.3*</td>
<td>1.57±0.3†</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Projected EOa, cm²</td>
<td>1.89±0.25</td>
<td>2.17±0.3</td>
<td>1.83±0.2*</td>
<td>1.61±0.21†</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Measured EOAi, cm²/m²</td>
<td>1.11±0.23</td>
<td>1.26±0.2</td>
<td>1.10±0.2*</td>
<td>0.83±0.1*†</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Projected EOAi, cm²/m²</td>
<td>1.10±0.17</td>
<td>1.35±0.1</td>
<td>1.05±0.1*</td>
<td>0.84±0.1*†</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

PA indicates pulmonary arterial; EOAi, indexed effective orifice area. Data are mean±SD.

*Significant difference from nonsignificant PPM group.
†Significant difference from Moderate PPM group.

1-Year Postoperative Echocardiographic Data in a Subset of 182 Patients
Overall survival after MVR

For patients with severe PPM, 6-year survival (74.5%) and 12-year survival (63.7%) were significantly less than for patients with moderate PPM (84.1% and 76.2%; P =0.027) or nonsignificant PPM (90.2% and 82.4%; P= 0.002)
### Predictors of Mortality in Univariate and Multivariate Analyses in the Whole Cohort

<table>
<thead>
<tr>
<th>Variables</th>
<th>Patients With Variables, n (%)</th>
<th>Univariate Analysis</th>
<th>Multivariate Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$P$</td>
<td>HR (95% CI)</td>
</tr>
<tr>
<td><strong>Preoperative variables</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>929 (100)</td>
<td>&lt;0.01</td>
<td>1.04 (1.0–1.1)</td>
</tr>
<tr>
<td>Female</td>
<td>566 (60.9)</td>
<td>0.19</td>
<td>0.9 (0.6–1.3)</td>
</tr>
<tr>
<td>Body surface area</td>
<td>929 (100)</td>
<td>0.23</td>
<td>0.5 (0.2–1.3)</td>
</tr>
<tr>
<td>NYHA functional class IV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Operative variables</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Renal failure</td>
<td>169 (18.2)</td>
<td>&lt;0.0001</td>
<td>3.2 (2.3–4.4)</td>
</tr>
<tr>
<td>Chronic lung disease</td>
<td>174 (18.7)</td>
<td>0.002</td>
<td>1.8 (1.2–2.5)</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>31/2 (40)</td>
<td>0.02</td>
<td>0.6 (0.5–0.9)</td>
</tr>
<tr>
<td>Mitral stenosis</td>
<td>459 (49.4)</td>
<td>0.04</td>
<td>0.7 (0.5–0.9)</td>
</tr>
<tr>
<td>ACC time &gt;80 min</td>
<td>387 (41.6)</td>
<td>&lt;0.0001</td>
<td>2.1 (1.5–3)</td>
</tr>
<tr>
<td>Concomitant CABG</td>
<td>274 (29.5)</td>
<td>&lt;0.0001</td>
<td>2.3 (1.7–3.2)</td>
</tr>
<tr>
<td>CPB time &gt;120 min</td>
<td>305 (32.8)</td>
<td>&lt;0.0001</td>
<td>2.2 (1.6–3.1)</td>
</tr>
<tr>
<td>Bioprosthesis</td>
<td>140 (15.1)</td>
<td>0.007</td>
<td>1.7 (1.2–2.5)</td>
</tr>
<tr>
<td>Moderate PPM</td>
<td>644 (69)</td>
<td>0.09</td>
<td>1.5 (0.9–2.4)</td>
</tr>
<tr>
<td>Severe PPM</td>
<td>81 (9)</td>
<td>0.006</td>
<td>2.4 (1.3–4.5)</td>
</tr>
</tbody>
</table>

Severe PPM was an independent predictor of mortality after mitral valve replacement.

3-step algorithm
(preoperative evaluation)

Step 1: Calculation of the patient’s BSA.

Step 2: Reference to the specific table for identification of the adequate valvular EOA according to the patient’s BSA.

Step 3: Selection of the most appropriate type and size of valve prosthesis according to the target iEOA.

Additionally, different surgical strategies have been advocated in order to minimize the risk of PPM, including routine enlargement of the aortic root, supra-annular prosthesis implantation, and the use of stentless bioprostheses, aortic homografts, or pulmonary Autografts.
Aortic valve replacement

(170cm, 68kg, if PPM: 0.85cm²/m²)

**Step 1:** Calculation of the patient’s BSA.

**Step 2:** Reference to the specific table for identification of the adequate valvular EOA according to the patient’s BSA. (1.8 X 0.85 = 1.53cm²)

**Step 3:** Selection of the most appropriate type and size of valve prosthesis according to the target iEOA.

(Mechanical: Carbomedics: 21mm
Bioprosthetic: Capentier-Edwards Perimount 23mm)
Conclusions

• PPM is a common and modifiable risk factor leading to worse hemodynamic function, more cardiac events, and lower survival.

• The projected indexed EOA should be systematically calculated at the time of the operation to estimate the risk of PPM.
Thank you for your attention!