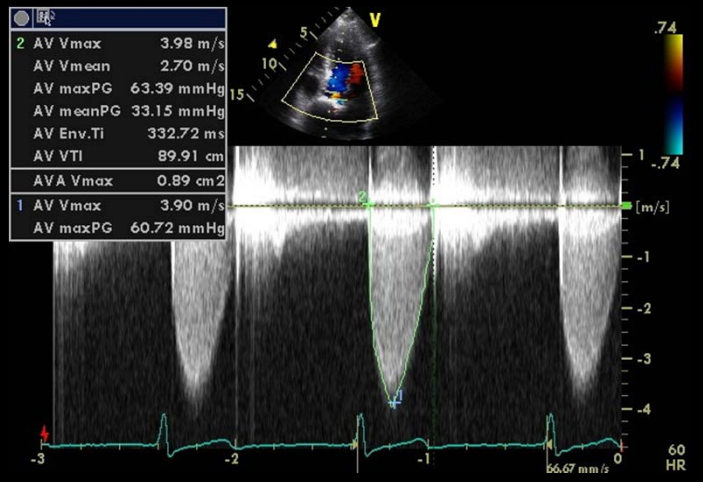
Echocardiographic evaluation of Patients–Prosthesis Mismatch

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

	Patient number				
	1	2	3	4	5
Body surface area (m^2)	1.5	1.75	2.0	2.25	2.5
Cardiac output (l/min)	4.5	5.25	6.0	6.75	7.5
Valve EOA (cm^2)	1.3	1.3	1.3	1.3	1.3
Mean pressure gradient (mm Hg)	13	17	22	28	35

For this simulation, mean pressure gradient was calculated assuming a cardiac index of 3 l/min/m^2, 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 Dumesnil[5] with permission of Remedica Publishing.

Pibarot, P.et.al.Heart 2006;92:1022–1029

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

Rahimtoola SH. *Circulation. 1978;58:20-4.*

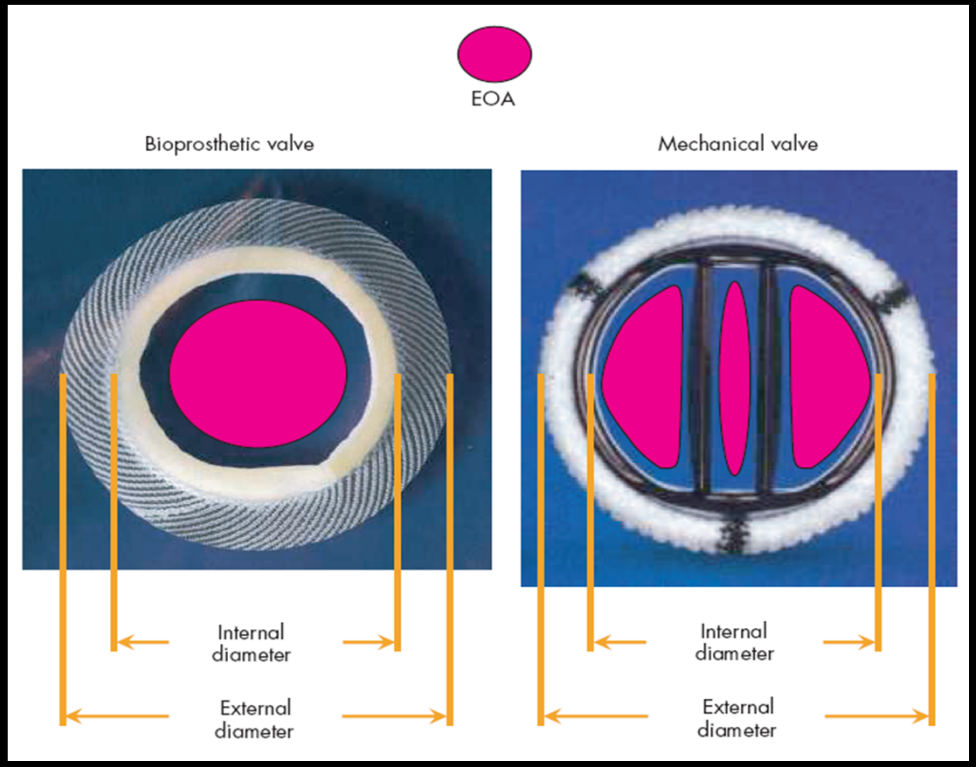
Parameters are used to define PPM

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.

Pibarot, P.et.al.Heart 2006;92:1022–1029

Comparison of geometric orifice area (GOA) and effective orifice area (EOA) values among different sizes of a commonly implanted bioprosthetic and mechanical valve.

Parameter	CE-19	SJM-19	CE-21	SJM-21	CE-23	SJM-23
GOA	1.96	1.63	2.9	2.06	3.9	2.55
EOA	0.9	1.1	1.1	1.5	1.5	2.13

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

Generally valve area regardless of type : GOA > EOA

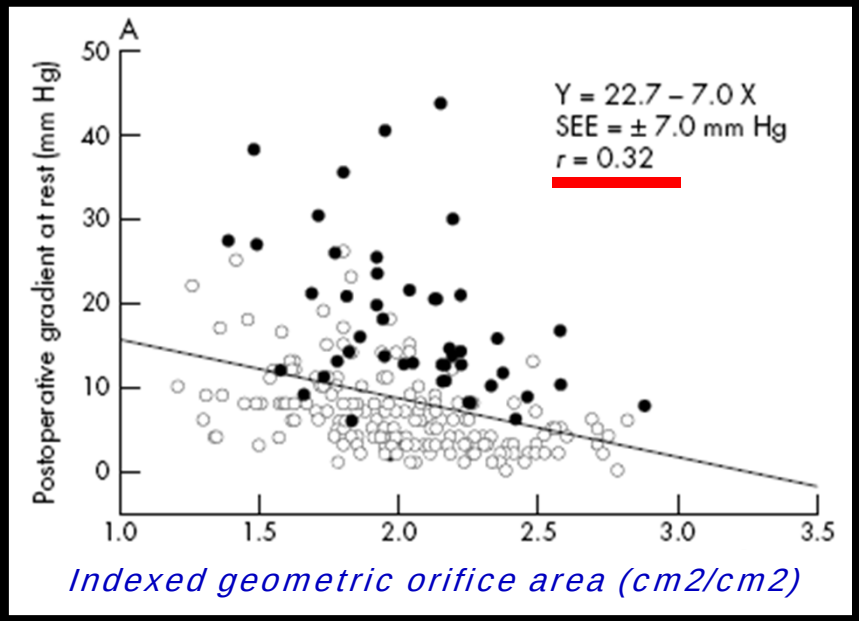
The Journal of Heart Valve Disease 2004;13 (Supplement 1): S59-S62

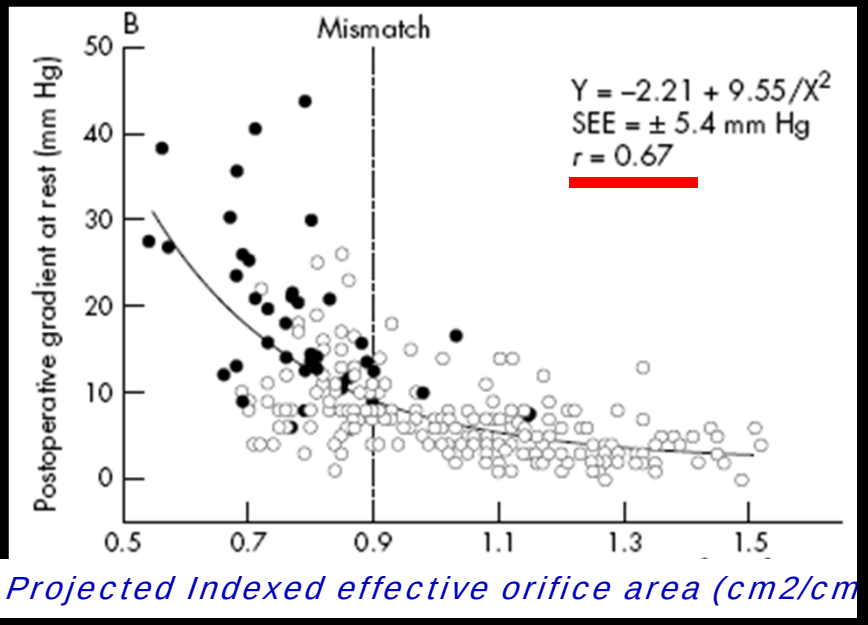
Normal reference values of EOAs for prosthetic valves (in vivo)*

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

*Expressed as mean values available in the literature.

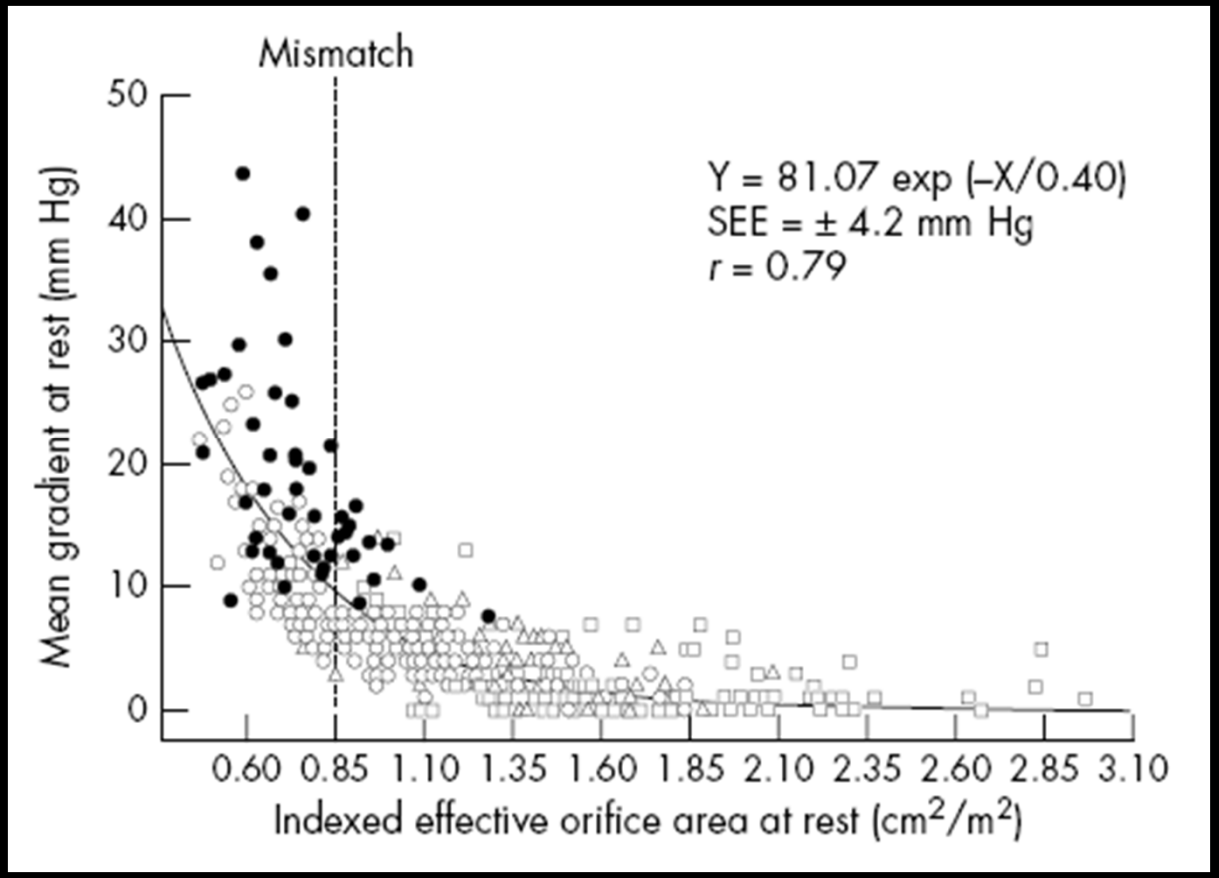
Correlation between postop. mean gradient and parameters calculated at the time of operation





Pibarot.P.et.al. Heart 2006;92:1022–1029

The indexed EOA is the only parameter that has been found to consistently correlate with postoperative gradients.



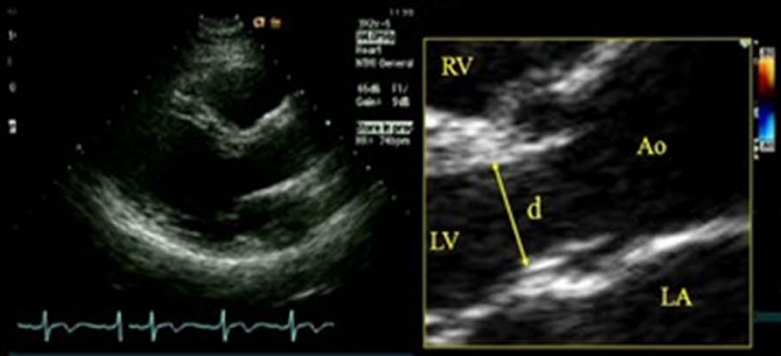
Correlation between mean transvalvar gradient and indexed effective orifice area in patients with a stented bioprosthesis (n = 51; solid circles), a stentless bioprosthesis (n = 194; open circles), an aortic homograft (n = 55; triangles), and a pulmonary autograft (n = 96; squares). Several points overlap. Reproduced from Pibarot and Dumesnil with permission of the American College of Cardiology.

$EOA_{Pr\ AV} = SV_{LVO} / TVI_{Pr\ AV}$

Calculate continuity equation when using echocardiography

LVOT (left ventricle outflow tract) 면적 :

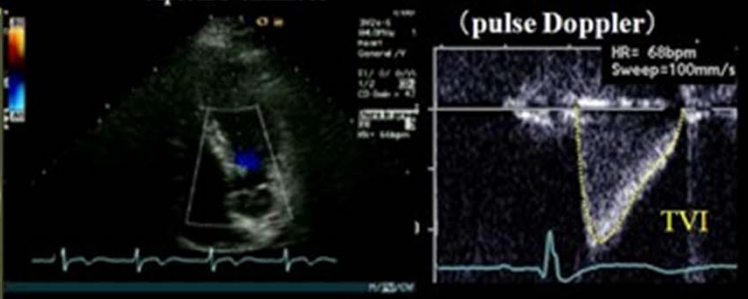
Para-sternal long axis



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

LVOT velocity and TVI 측정

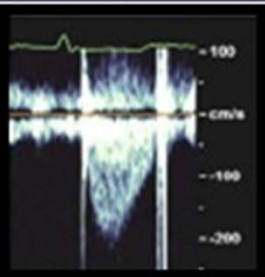
Apical 5 chamber



Stroke Volume = LVOT area × TVI

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

TVI_{PrAV} = TVI across the prosthesis using CW Doppler



PPM has been the indexed EOA

$$IEOA = \frac{\text{EOA of the prosthesis}}{\text{Patient's body surface area (BSA)}}$$

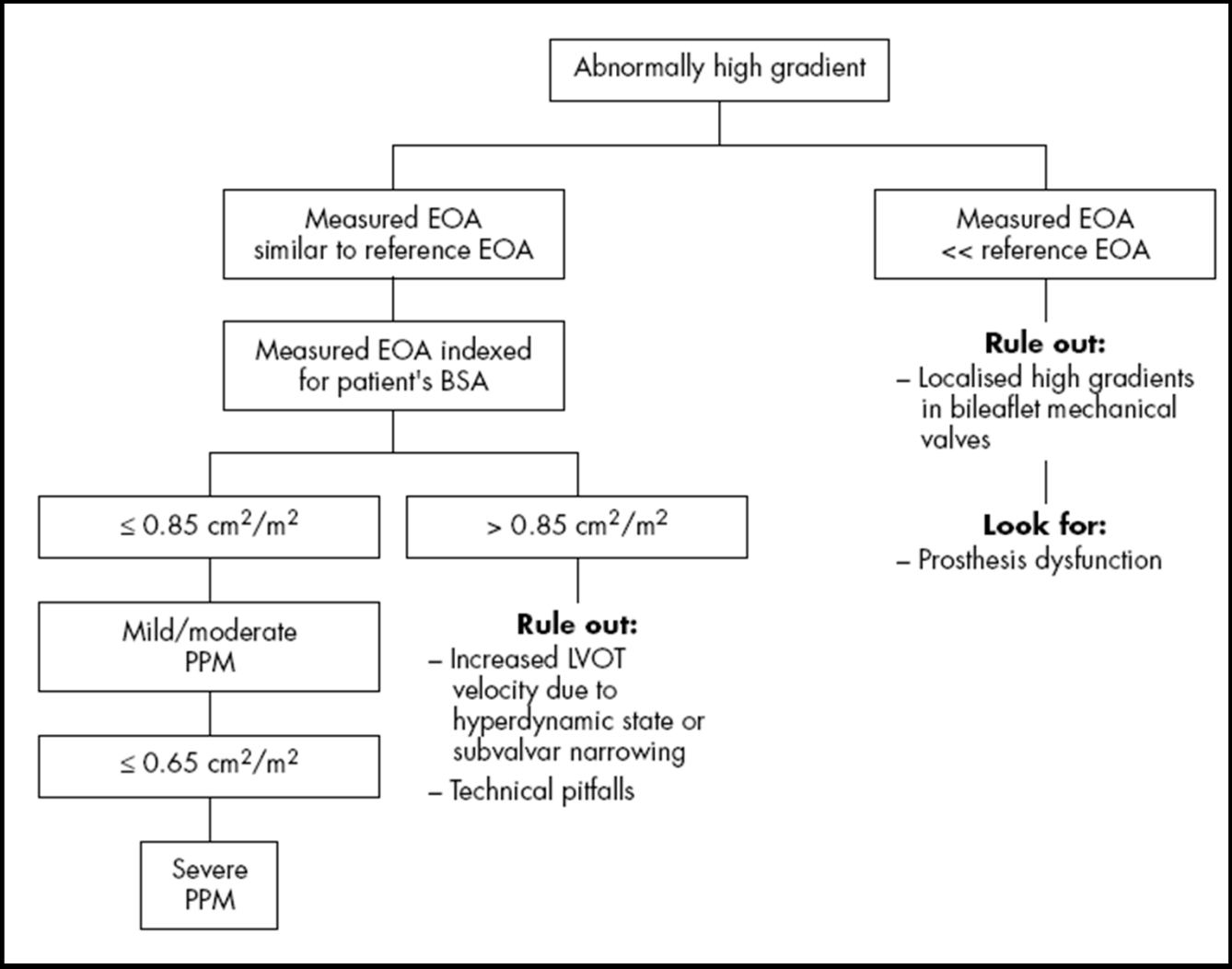
EOA (effective orifice area) = physiologic parameter derived from hydraulic principles and corresponding to the actual area occupied by flow as it exit the valve; directly related to hemodynamics and gradients

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

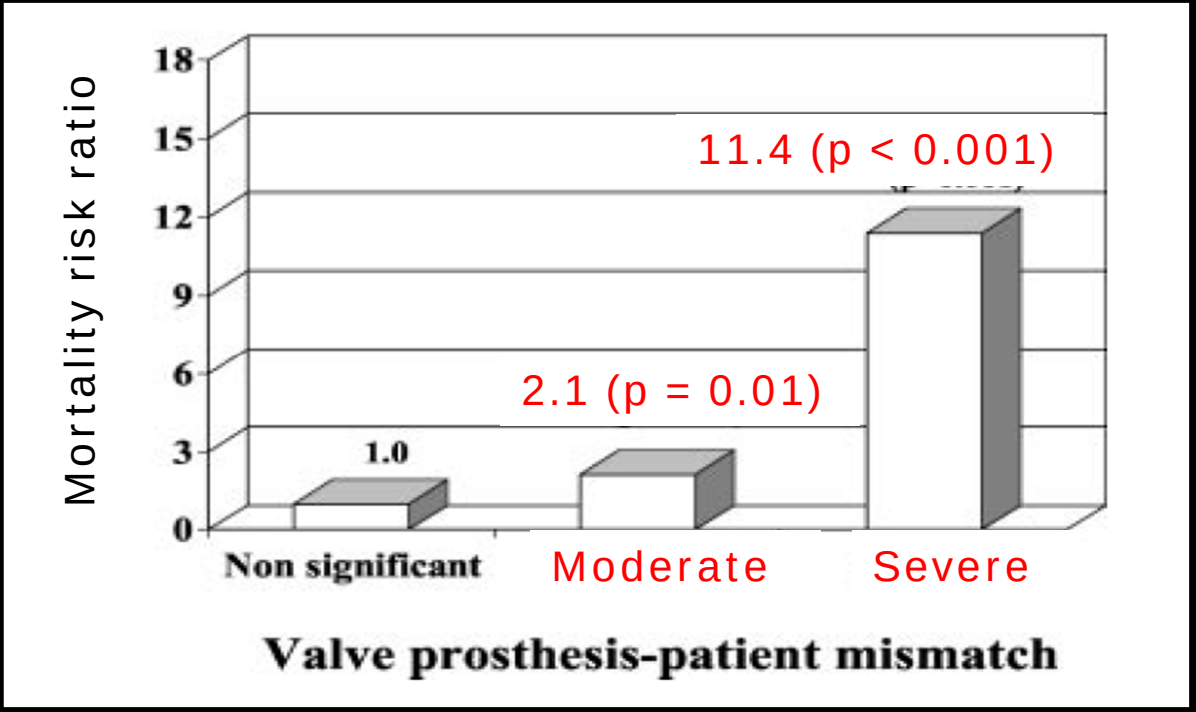
Abnormally high transvalvular pressure gradients after aortic valve replacement



Impact of Valve Prosthesis-Patient Mismatch on Short-Term Mortality After Aortic Valve Replacement

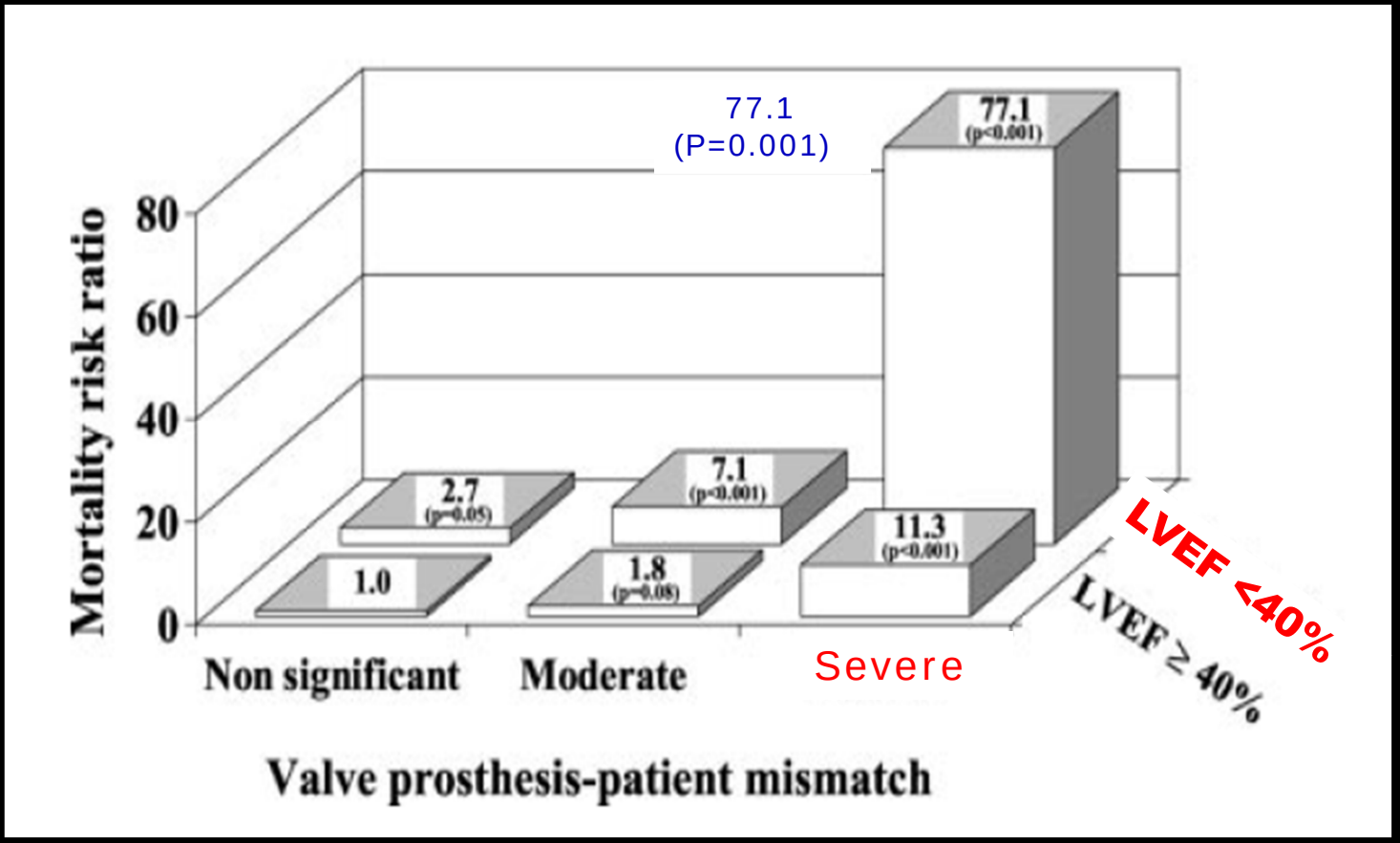
Claudia Blais, BSc; Jean G. Dumesnil, MD; Richard Baillot, MD; Serge Simard, MS;
Daniel Doyle, MD; Philippe Pibarot, DVM, PhD

- *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 30days after operation*



Blais. C.et.al. Circulation. 2003;108:983-988

Relative risk ratio for short-term mortality according to valve PPM and preoperative LV EF



Blais. C.et.al. Circulation. 2003;108:983-988

Impact of Prosthesis-Patient Mismatch on Cardiac Events and Midterm Mortality After Aortic Valve Replacement in Patients With Pure Aortic Stenosis

Giordano Tasca, MD; Zen Mhagna, MD; Silvano Perotti, MD; Pietro Berra Centurini, MD; Tony Sabatini, MD; Andrea Amaducci, MD; Federico Brunelli, MD; Marco Cirillo, MD; Margherita Dalla Tomba, MD; Eugenio Quiani, MD; Giovanni Troise, MD; Philippe Pibarot, DVM, PhD

- *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

	Model 1		Model 2	
Variable	*P*	HR (95% CI)	*P*	HR (95% CI)
Preoperative variables				
History of heart failure	0.023	2.5 (1.1–5.4)	0.04	2.3 (1.02–5.1)
Sinus rhythm	0.006	0.2 (0.09–0.52)	0.001	0.2 (0.1–0.48)
Operative variables				
EOAi, cm^2/m^2	…	…	0.04	0.67 (0.46–0.97)*
PPM (EOAi ≤0.80 cm^2/m^2)	0.004	4.2 (1.6–11.3)	…	…

Cardiac Events

	Model 1		Model 2	
Variable	*P*	HR (95% CI)	*P*	HR (95% CI)
Preoperative variables				
Sinus rhythm	0.003	0.3 (0.13–0.65)	0.001	0.25 (0.1–0.6)
Severe preoperative LV hypertrophy	0.018	2.8 (1.2–6.6)	0.01	3.0 (1.3–7.1)
Preoperative NYHA	0.045	1.9 (1.02–3.8)	0.03	2.1 (1.2–3.1)
Operative variables				
EOAi	…	…	0.003	0.63 (0.47–0.84)*
PPM (EOAi ≤0.80 cm^2/m^2)	0.003	3.2 (1.6–6.8)	…	…

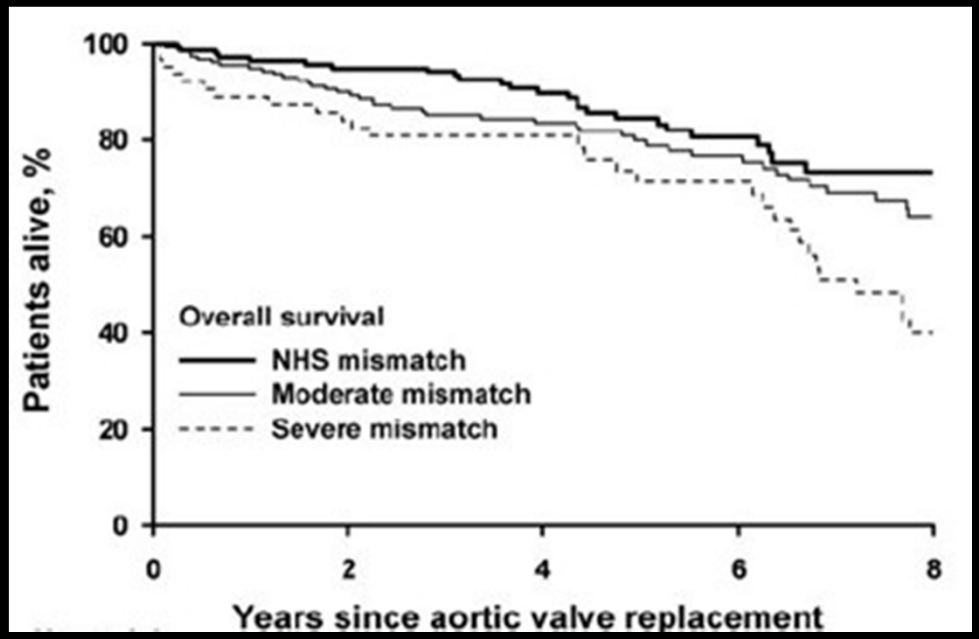
Cardiac events: cardiac death,sudden death,heart failure, syncope. angina

Tasca.G. et.al *Circulation. 2006;113:570-576*

Impact of Prosthesis-Patient Mismatch on Long-Term Survival in Patients With Small St Jude Medical Mechanical Prostheses in the Aortic Position

Dania Mohty-Echahidi, MD; Joseph F. Malouf, MD; Steve E. Girard, MD, PhD; Hartzell V. Schaff, MD; Diane E. Grill, MS; Maurice E. Enriquez-Sarano, MD; Fletcher A. Miller, Jr, MD

- *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).*

Circulation. 2006;113:420-426

Mitral valve

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

Rahimtoola SH et.al. Br Heart J 1981;45:331–5.

- ***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**

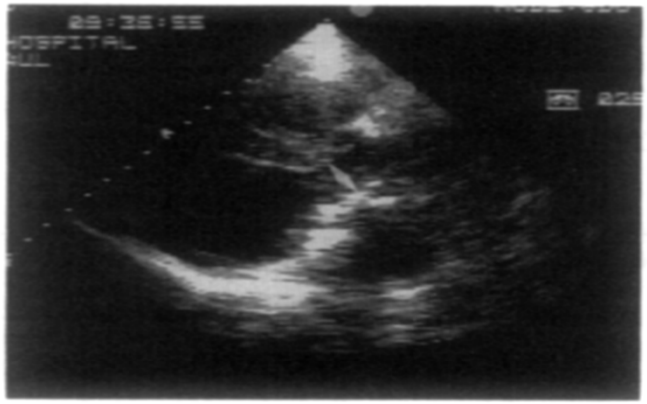
is not valid in prosthetic valves, because of its dependence on LV and LA compliance and initial LA pressure.

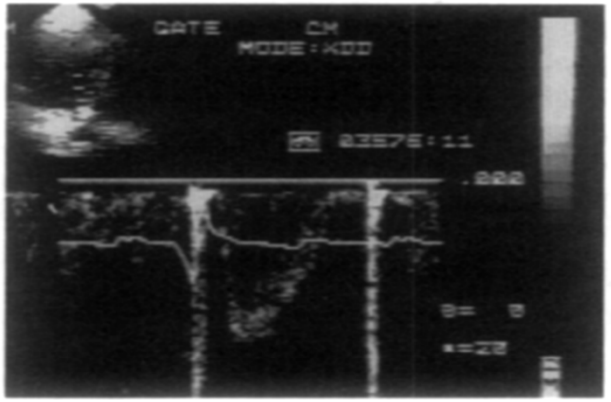
3. **Use MV mean gradient (indirect)**

Doppler Echocardiographic Assessment With the Continuity Equation of St. Jude Medical Mechanical Prostheses in the Mitral Valve Position

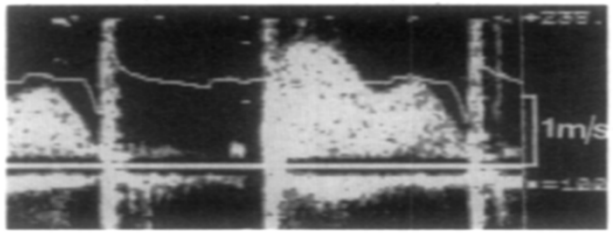
Jamil N. Bitar, MD, Marcel E. Lechin, MD, Gabriel Salazar, MD, and William A. Zoghbi, MD

A patient with documented St. Jude prosthetic mitral valve obstruction and previous myocardial infarction





- Mean Grad. = 8 mmHg
- $MVA_{PHT} = \frac{220}{100} = 2.2 cm^2$
- $EOA_{CON} = \frac{SV}{TVI_{Mv}} = \frac{51\ cm^3}{62\ cm} = 0.82 cm^2$

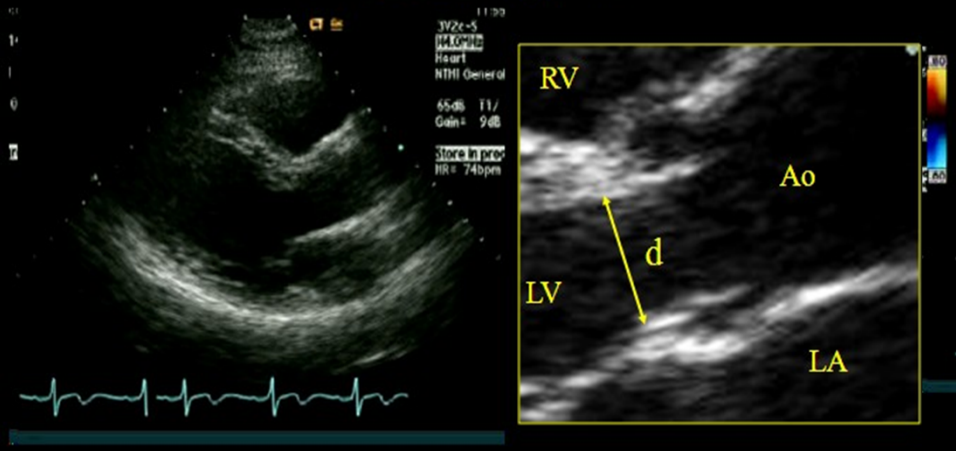


Jamil N.et.al. Am J Cardiol 1995;76:287-293

$EOA_{Pr\ MV} = SV_{LVO} / TVI_{Pr\ MV}$

LVOT (left ventricle outflow tract) 면적 :

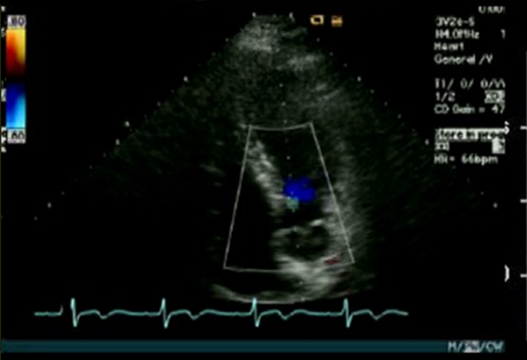
Para-sternal long axis



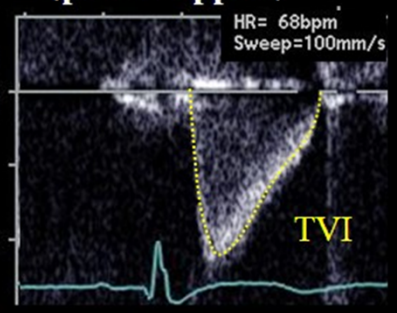
$$\text{LVOT area } (cm^2) = (\frac{d}{2})^2 \times \pi$$

LVOT velocity and TVI 측정

Apical 5 chamber



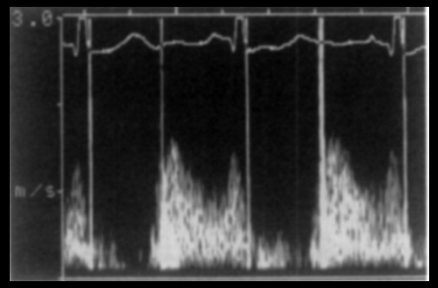
AV annulus 혈류속도 (pulse Doppler)



Stroke Volume = LVOT area × TVI

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

TVI_{PrMV} = 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*

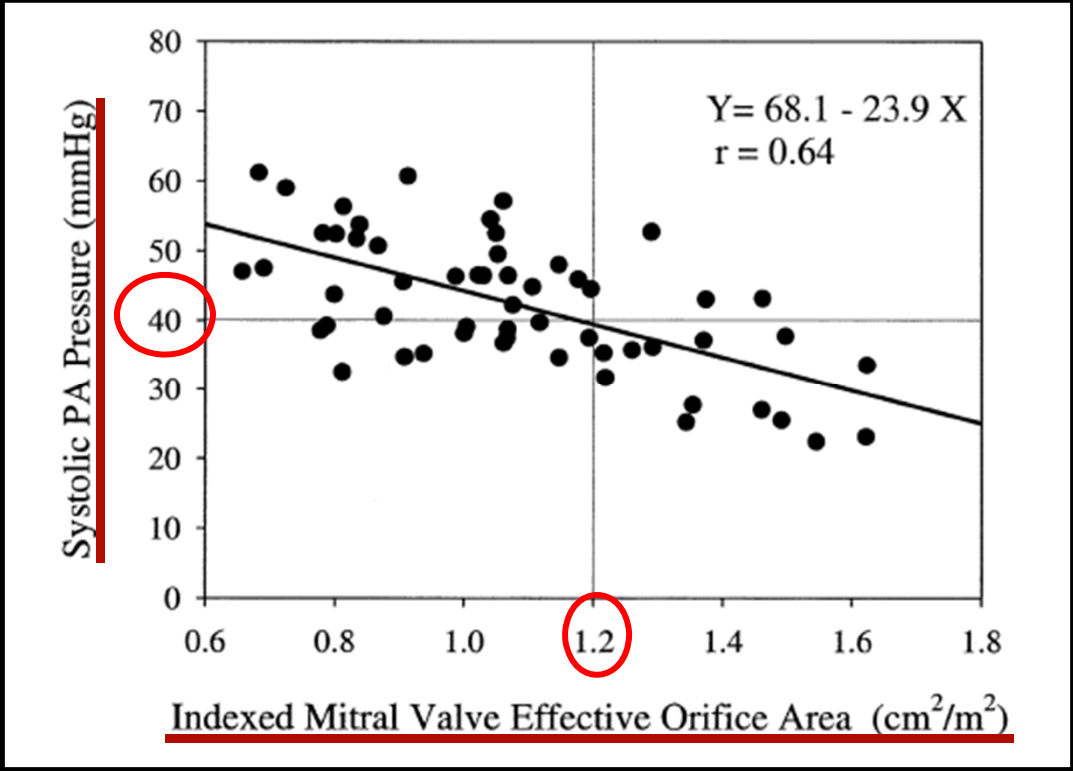
Impact of Valve Prosthesis-Patient Mismatch on Pulmonary Arterial Pressure After Mitral Valve Replacement

Mingzhou Li, MD, PHD, Jean G. Dumesnil, MD, FACC, Patrick Mathieu, MD, Philippe Pibarot, DVM, PHD, FACC

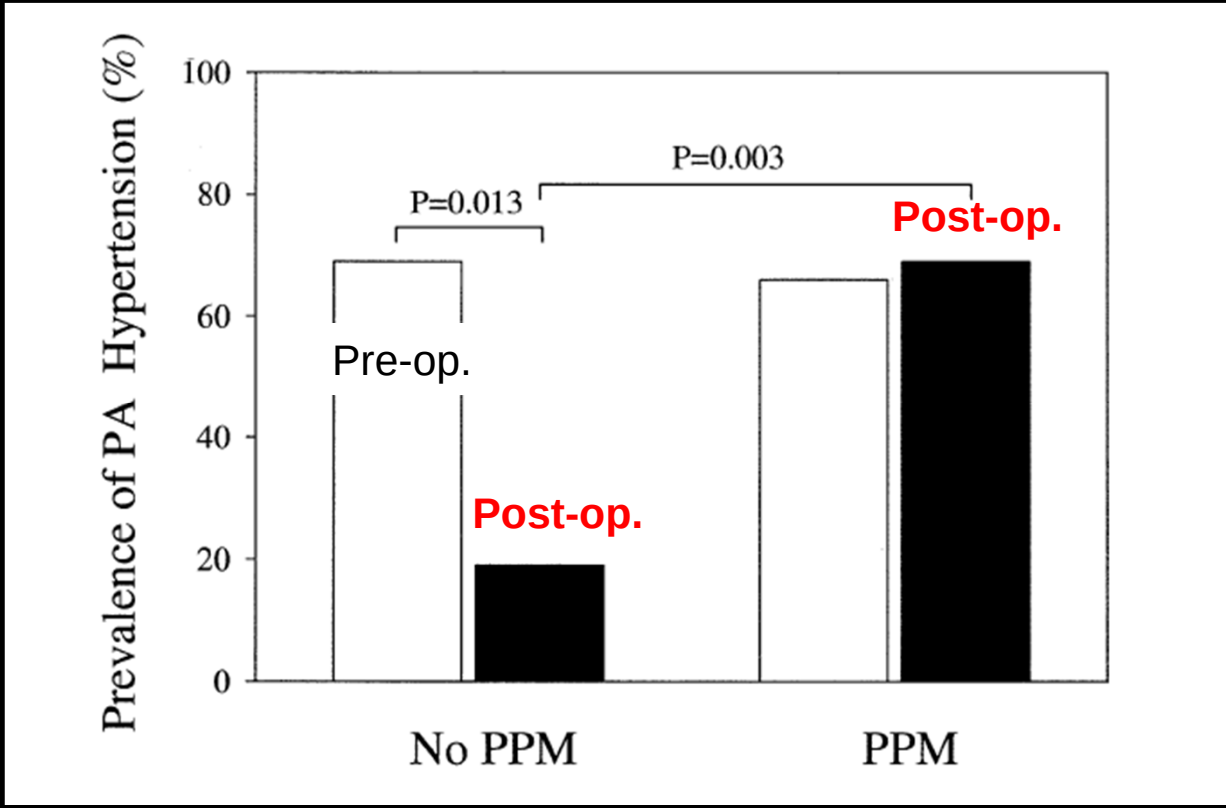
- *56 patients with normally functioning mitral prosthetic valves*
  Systolic PA pressure : by Doppler echocardiography
- *iEOA : the continuity equation and indexed for BSA*
- *PA hypertension : systolic PA pre. 40 mm Hg (54%)*
  PPM : an indexed EOA < 1.2 cm2/m2 (71%)
- *The average systolic PA pressure and prevalence of PA hypertension were 34 ± 8 mm Hg and 19% in patients with no PPM versus 46 ± 8 mm Hg and 68% in patients with PPM (p < 0.001)*

Li. M et.al. J Am Coll Cardiol 2005;45:1034–40

Correlation between systolic PA pressure and indexed mitral valve EOA



Li. M et.al. J Am Coll Cardiol 2005;45:1034–40



Persistent PA hypertension is frequent after MVR and strongly associated with the presence of PPM

Li. M et.al. J Am Coll Cardiol 2005;45:1034–40

Impact of Prosthesis-Patient Mismatch on Survival After Mitral Valve Replacement

Julien Magne, MSc; Patrick Mathieu, MD, FRCPC; Jean G. Dumesnil, MD, FRCPC; David Tanné, Eng; François Dagenais, MD, FRCPC; Daniel Doyle, MD, FRCPC; Philippe Pibarot, DVM, PhD

- ***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%***

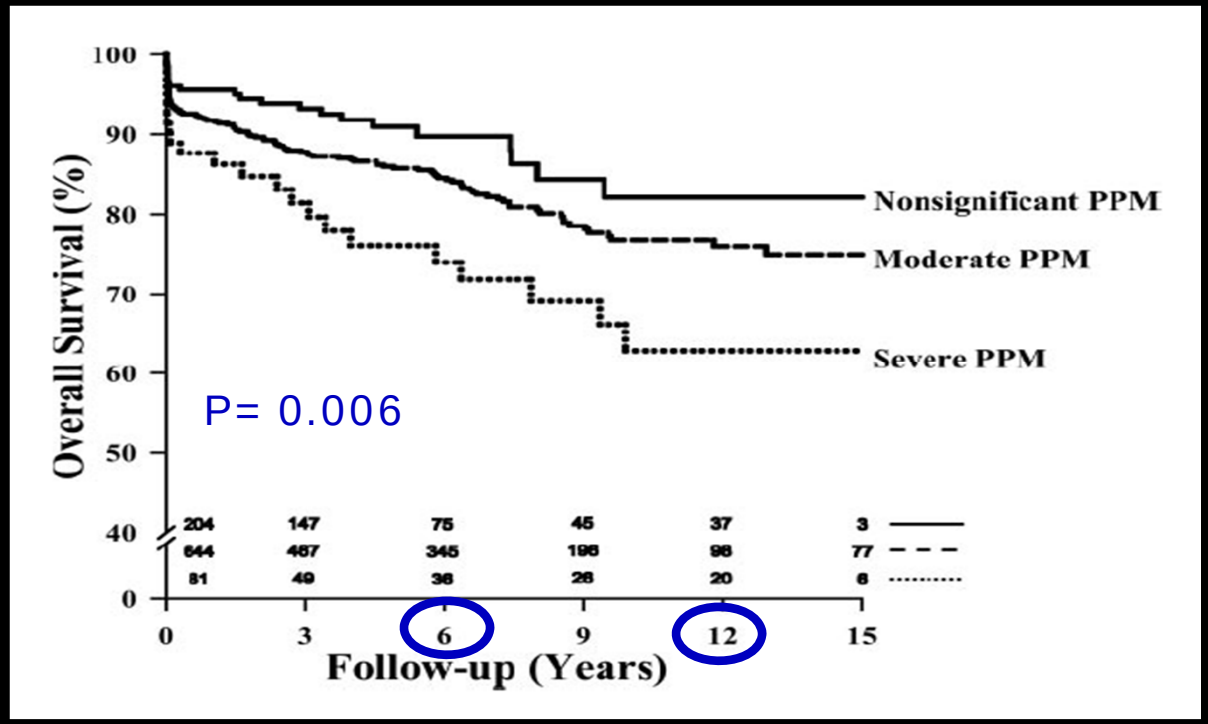
Variables	All Patients (n=182)	Nonsignificant PPM (n=41)	Moderate PPM (n=124)	Severe PPM (n=17)	*P*
Mitral peak gradient, mm Hg	9.7±3.5	8±2.4	9.8±3.3*	13.4±4.6*†	<0.001
Mitral mean gradient, mm Hg	3.5±1.7	2.6±1.0	3.9±1.3*	6.0±2.6*†	<0.001
Systolic PA pressure, mm Hg	41±9	38±9	41±8*	49±12*†	<0.001
Measured EOA, cm^2	1.9±0.36	2.01±0.3	1.90±0.3*	1.57±0.3*†	<0.001
Projected EOA, cm^2	1.89±0.25	2.17±0.3	1.83±0.2*	1.61±0.21*†	<0.001
Measured EOAi, cm^2/m^2	1.11±0.23	1.26±0.2	1.10±0.2*	0.83±0.1*†	<0.001
Projected EOAi, cm^2/m^2	1.10±0.17	1.35±0.1	1.05±0.1*	0.84±0.1*†	<0.001

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

Magne. *J. et.al .Circulation. 2007;115:1417-1425*

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

Variables	Patients With Variables, n (%)	Univariate Analysis		Multivariate Analysis	
		P	HR (95% CI)	*P*	HR (95% CI)
Preoperative variables					
Age	929 (100)	<0.01	1.04 (1.0–1.1)	0.03	1.02 (1.002–1.04)
Female	566 (60.9)	0.19	0.9 (0.6–1.3)	0.04	0.64 (0.42–0.98)
Body surface area	929 (100)	0.23	0.5 (0.2–1.3)	0.0003	0.1 (0.03–0.3)
NYHA functional class IV					
Moderate PPM	644 (69)	0.09	1.5 (0.9–2.4)	0.06	1.7 (0.98–2.8)
Severe PPM	81 (9)	0.006	2.4 (1.3–4.5)	0.003	3.2 (1.5–6.8)
Renal failure	169 (18.2)	<0.0001	3.2 (2.3–4.4)	0.0003	1.98 (1.4–2.9)
Chronic lung disease	174 (18.7)	0.0025	1.8 (1.2–2.5)	...	...
Atrial fibrillation	372 (40)	0.02	0.6 (0.5–0.9)	...	...
Mitral stenosis	459 (49.4)	0.04	0.7 (0.5–0.9)	...	...
Operative variables					
ACC time >80 min	387 (41.6)	<0.0001	2.1 (1.5–3)	0.0006	1.8 (1.3–2.6)
Concomitant CABG	274 (29.5)	<0.0001	2.3 (1.7–3.2)	...	...
CPB time >120 min	305 (32.8)	<0.0001	2.2 (1.6–3.1)	...	...
Bioprosthesis	140 (15.1)	0.007	1.7 (1.2–2.5)	...	...
Moderate PPM	644 (69)	0.09	1.5 (0.9–2.4)	0.06	1.7 (0.98–2.8)
Severe PPM	81 (9)	0.006	2.4 (1.3–4.5)	0.003	3.2 (1.5–6.8)

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

Magne. *J. et.al .Circulation. 2007;115:1417-1425*

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)

Valve type	Prosthetic valve size (mm) 19	21	23	25	27	29	Reference
Stented bioprosthetic valves							
Medtronic Mosaic	1.20	1.22	1.38	1.65	1.80	2.00	6
Hancock II	NA	1.18	1.33	1.46	1.55	1.60	6
Carpentier-Edwards Perimount	1.10	1.30	1.50	1.80	1.80	NA	6
Stentless bioprosthetic valves							
Medtronic Freestyle	1.15	1.35	1.48	2.00	2.32	NA	6
St Jude Medical Toronto SPV	–	1.30	1.50	1.70	2.00	2.50	6
Prima Edwards	0.80	1.10	1.50	1.80	2.30	2.80	6
Mechanical valves							
Medtronic-Hall	1.19	1.34	NA	NA	NA	NA	6
St Jude Medical Standard	1.04	1.38	1.52	2.08	2.65	3.23	6
St Jude Medical Regent	1.60	2.00	2.20	2.50	3.60	4.40	40
MCRI On-X	1.50	1.70	2.00	2.40	3.20	3.20	41
Carbomedics	1.00	1.54	1.63	1.98	2.41	2.63	6
Sorin Bicarbon	NA	1.66	1.96	NA	NA	NA	42

*Expressed as mean values available in the literature.

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

(Mechnical : 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 !