Echocardiographic Evaluation of Prosthetic Valves

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The 1st valve replacement in 1960

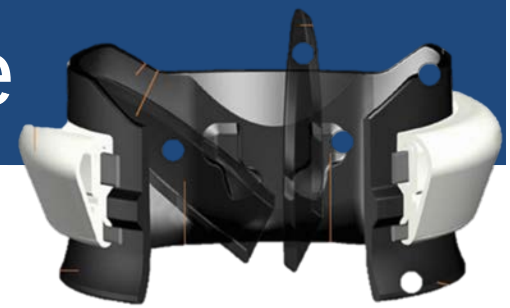
It will work: The first successful mitral valve replacement ☆

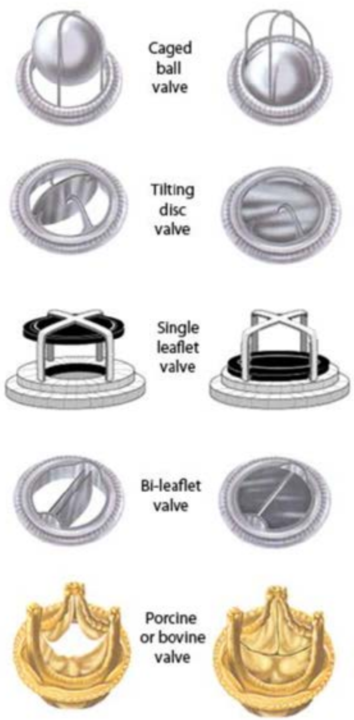
Nina S. Braunwald, MD

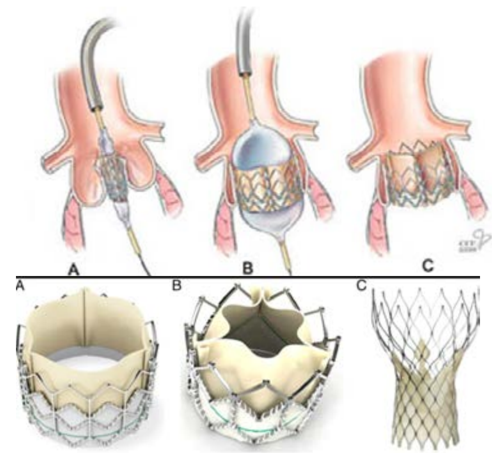
Abstract

n 1959, a prosthetic mitral valve of flexible polyurethane with Teflon chordae endineae was designed and fabricated. After a series of experiments in dogs :arried out at the Clinic of Surgery at the National Heart Institute, on March 11, I960, this valve was used as a total replacement of the mitral valve of a 44-year-old woman with mitral regurgitation. After an uneventful postoperative course, she vas discharged from the hospital and did well thereafter, but died suddenly, oresumably of an arrhythmia, 4 months after operation.

There is no perfect valve







"*they have introduced other, new problems into clinical medicine, so that in effect*, the **patient is exchanging one disease process for another**"

Basic Principles

- By their design, almost all replacement valves are **obstructive** compared with normal native valves
- Most mechanical valves and many biologic valves are associated with trivial or mild transprosthetic regurgitation **(physiologic regurgitation)**
- Because of **shielding and artifacts**, insonation of the valve esp regurgitant jets may be difficult and requires multiple angulations of the probe and the use of off-axis view

Normal Values for Implanted Aortic Valves

AORTIC VALVES	SIZE (mm)	PEAK GRADIENT (mm Hg)	MEAN GRADIENT (mm Hg)	EFFECTIVE ORIFICE AREA (cm^2)
Carpentier-Edwards Pericardial	19	32.1 ± 3.4	24.2 ± 8.6	1.2 ± 0.3
Stented bovine pericardial	21	25.7 ± 9.9	20.3 ± 9.1	1.5 ± 0.4
	23	21.7 ± 8.6	13.0 ± 5.3	1.8 ± 0.3
	25	16.5 ± 5.4	9.0 ± 2.3	
Carpentier-Edwards Standard	19	43.5 ± 12.7	25.6 ± 8.0	0.9 ± 0.2
Stented porcine	21	27.7 ± 7.6	17.3 ± 6.2	1.5 ± 0.3
	23	28.9 ± 7.5	16.1 ± 6.2	1.7 ± 0.5
	25	24.0 ± 7.1	12.9 ± 4.6	1.9 ± 0.5
	27	22.1 ± 8.2	12.1 ± 5.5	2.3 ± 0.6
	29		9.9 ± 2.9	2.8 ± 0.5
Hancock	21	18.0 ± 6.0	12.0 ± 2.0	
Stented porcine	23	16.0 ± 2.0	11.0 ± 2.0	
	25	15.0 ± 3.0	10.0 ± 3.0	
Hancock II	21		14.8 ± 4.1	1.3 ± 0.4
Stented porcine	23	34.0 ± 13.0	16.6 ± 8.5	1.3 ± 0.4
	25	22.0 ± 5.3	10.8 ± 2.8	1.6 ± 0.4
	29	16.2 ± 1.5	8.2 ± 1.7	1.6 ± 0.2
Medtronic Mosaic	21		14.2 ± 5.0	1.4 ± 0.4
Stented porcine	23	23.8 ± 11.0	13.7 ± 4.8	1.5 ± 0.4
	25	22.5 ± 10.0	11.7 ± 5.1	1.8 ± 0.5
	27		10.4 ± 4.3	1.9 ± 0.1
	29		11.1 ± 4.3	2.1 ± 0.2
Medtronic-Hall	20	34.4 ± 13.1	17.1 ± 5.3	1.2 ± 0.5
Single tilting disc	21	26.9 ± 10.5	14.1 ± 5.9	1.1 ± 0.2
	23	26.9 ± 8.9	13.5 ± 4.8	1.4 ± 0.4
	25	17.1 ± 7.0	9.5 ± 4.3	1.5 ± 0.5
	27	18.9 ± 9.7	8.7 ± 5.6	1.9 ± 0.2
St. Jude Medical Standard	19	42.0 ± 10.0	24.5 ± 5.8	1.5 ± 0.1
Bileaflet	21	25.7 ± 9.5	15.2 ± 5.0	1.4 ± 0.4
	23	21.8 ± 7.5	13.4 ± 5.6	1.6 ± 0.4
	25	18.9 ± 7.3	11.0 ± 5.3	1.9 ± 0.5
	27	13.7 ± 4.2	8.4 ± 3.4	2.5 ± 0.4
	29	13.5 ± 5.8	7.0 ± 1.7	2.8 ± 0.5

Normal Values for Implanted Mitral Valves

MITRAL VALVES	SIZE (mm)	GRADIENT (mm Hg)	GRADIENT (mm Hg)	PEAK VELOCITY (m/sec)	PRESSURE HALF-TIME (msec)	ORIFICE AREA (cm^2)
Carpentier-Edwards *Stented bioprosthesis*	27		6 ± 2	1.7 ± 0.3	98 ± 28	
	29		4.7 ± 2	1.76 ± 0.27	92 ± 14	
	31		4.4 ± 2	1.54 ± 0.15	92 ± 19	
	33		6 ± 3		93 ± 12	
Carpentier-Edwards Pericardial *Stented bioprosthesis*	27		3.6	1.6	100	
	29		5.25 ± 2.36	1.67 ± 0.3	110 ± 15	
	31		4.05 ± 0.83	1.53 ± 0.1	90 ± 11	
	33		1	0.8	80	
Hancock I or not specified *Stented bioprosthesis*	27	10 ± 4	5 ± 2		115 ± 20	1.3 ± 0.8
	29	7 ± 3	2.46 ± 0.79		95 ± 17	1.5 ± 0.2
	31	4 ± 0.86	4.86 ± 1.69		90 ± 12	1.6 ± 0.2
	33	3 ± 2	3.87 ± 2			1.9 ± 0.2
Hancock II *Stented bioprosthesis*	27					2.21 ± 0.14
	29					2.77 ± 0.11
	31					2.84 ± 0.1
	33					3.15 ± 0.22
Medtronic-Hall *Tilting disc*	27			1.4	78	
	29			1.57 ± 0.1	69 ± 15	
	31			1.45 ± 0.12	77 ± 17	
St. Jude Medical *Bileaflet*	23		4	1.5	160	1
	25		2.5 ± 1	1.34 ± 1.13	75 ± 4	1.35 ± 0.17
	27	11 ± 4	5 ± 1.82	1.61 ± 0.29	75 ± 10	1.67 ± 0.17
	29	10 ± 3	4.15 ± 1.8	1.57 ± 0.29	85 ± 10	1.75 ± 0.24

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Physiologic Regurgitation

- **Washing jets** to prevent thrombus formation
- 10-15%
- Jets low in momentum
  - homogeneous in color,
  - aliasing mostly confined to the base of the jet.

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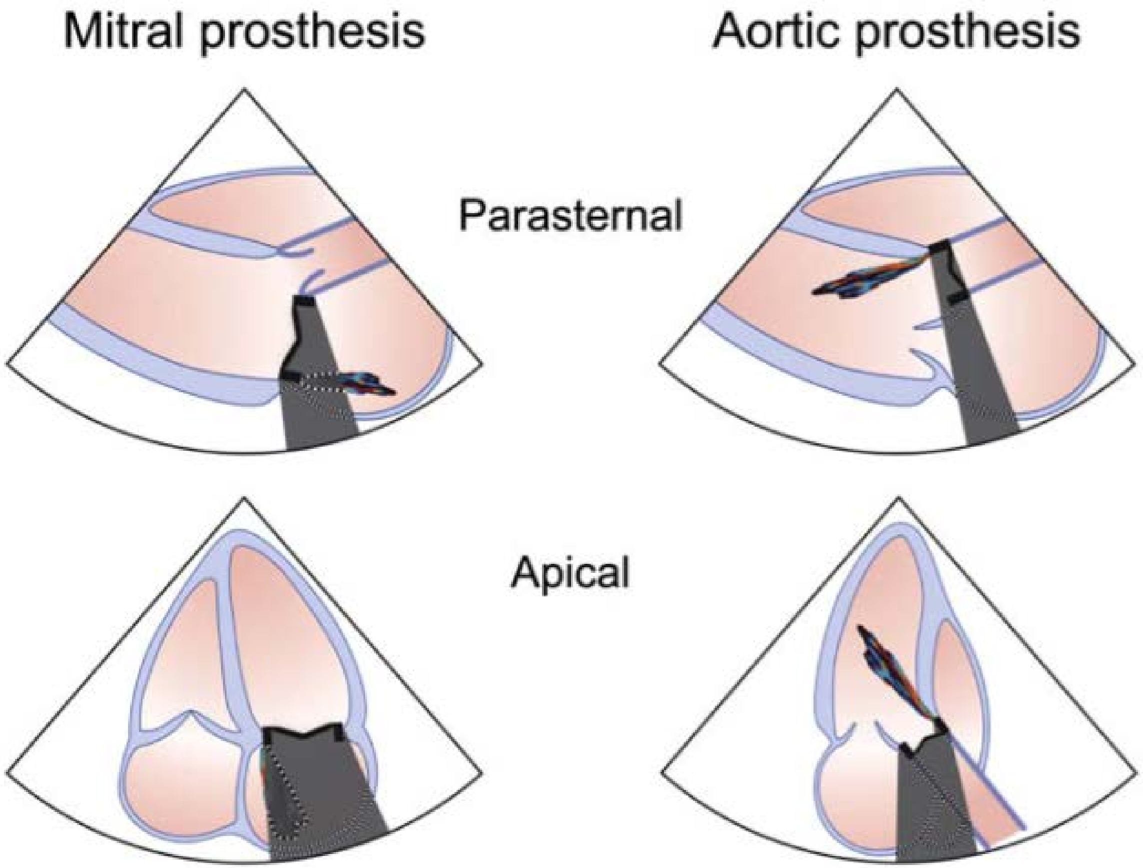
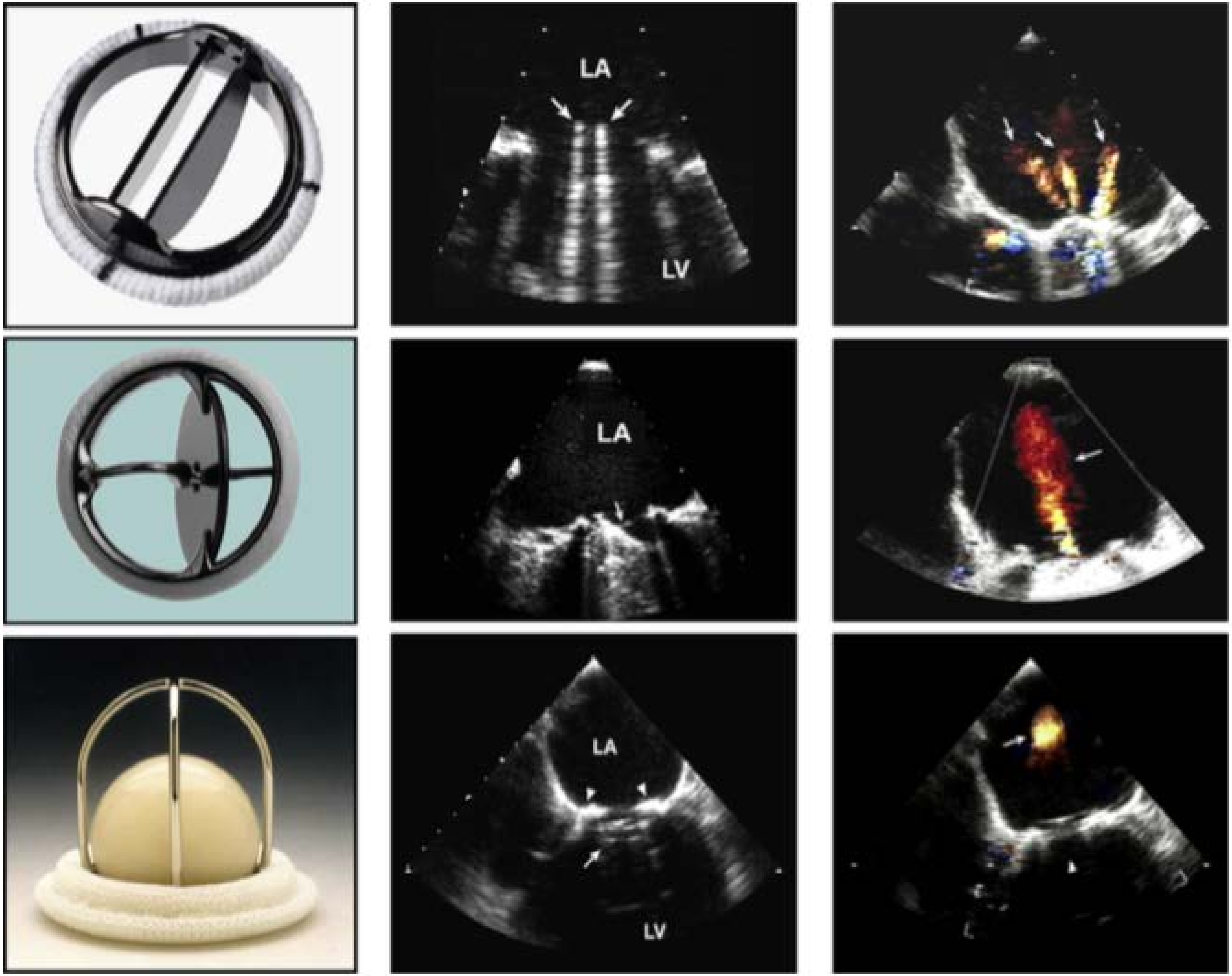
Shadowing

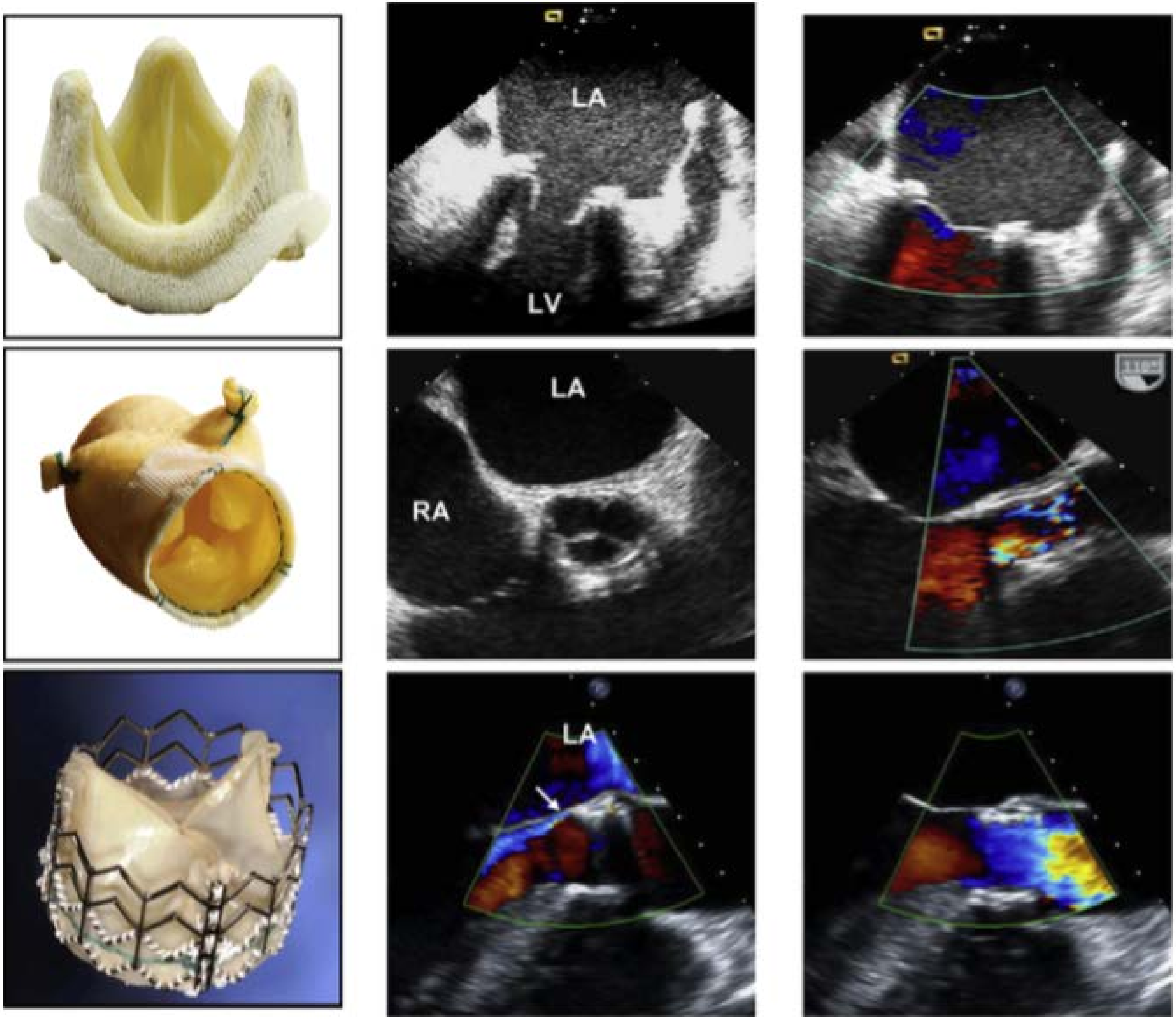


Types of Prosthetic Valves

Table 1 Types of prosthetic heart valves

Biologic		
	Stented	
		Porcine xenograft
		Pericardial xenograft
	Stentless	
		Porcine xenograft
		Pericardial xenograft
		Homograft (allograft)
		Autograft
	Percutaneous	
Mechanical		
	Bileaflet	
	Single tilting disc	
	Caged-ball	


LA
LV
LA
LA
LV



LA
LV
LA
RA
LA

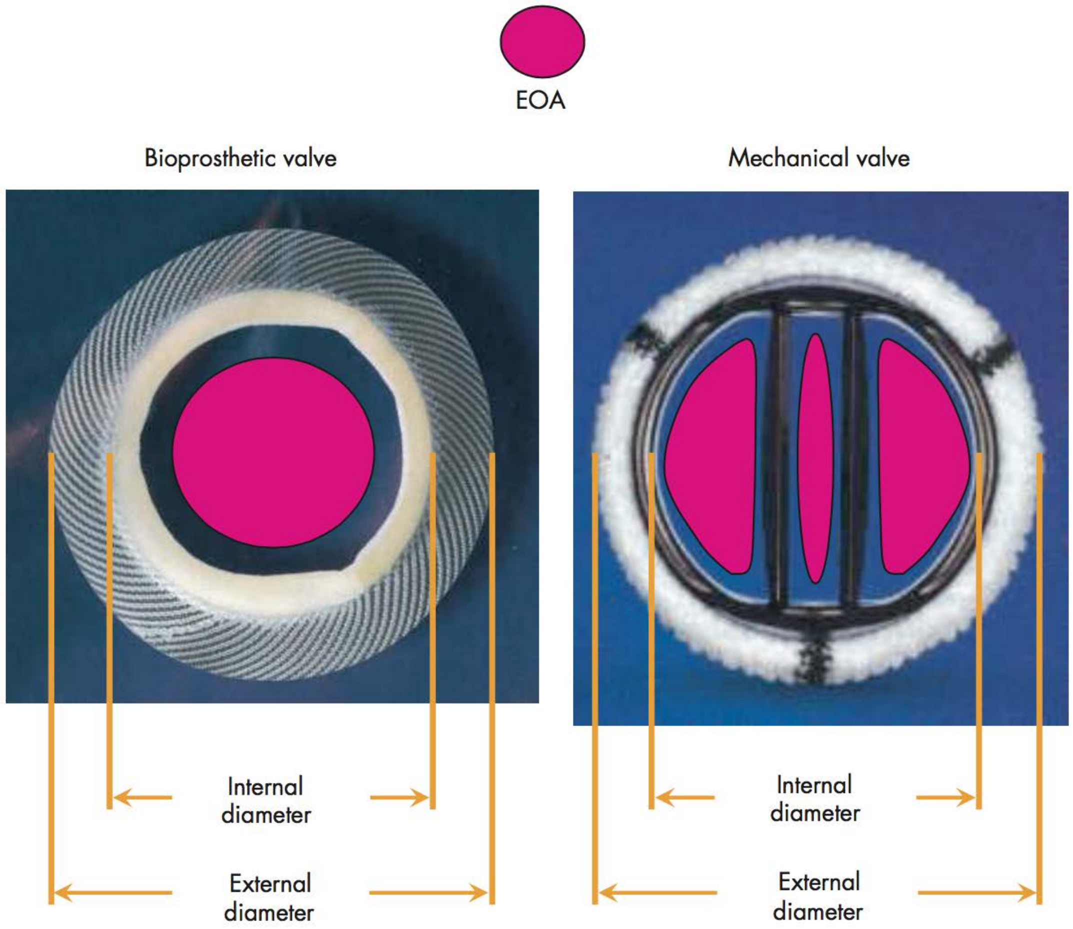
Table 2 Essential parameters in the comprehensive evaluation of prosthetic valve function

	Parameter
Clinical information	Date of valve replacement Type and size of the prosthetic valve Height, weight, body surface area Symptoms and related clinical findings Blood pressure and heart rate
Imaging of the valve	Motion of leaflets or occluder Presence of calcification on the leaflets or abnormal echo densities on the various components of the prosthesis Valve sewing ring integrity and motion
Doppler echocardiography of the valve	Contour of the jet velocity signal Peak velocity and gradient Mean pressure gradient VTI of the jet DVI Pressure half-time in MV and TV. EOA* Presence, location, and severity of regurgitation†
Other echocardiographic data	LV and RV size, function, and hypertrophy LA and right atrial size Concomitant valvular disease Estimation of pulmonary artery pressure
Previous postoperative studies, when available	Comparison of above parameters is particularly helpful in suspected prosthetic valvular dysfunction

PVM

heart rate of the cardiac cycles used for Doppler measurements is particularly **important in mitral and tricuspid prosthetic valves,** because the mean gradient is dependent on the diastolic filling period.

Valve Size is not equal to EOA



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Thrombus?
Pannus?
Vegetation ?

Opening and closing motion of the occluder

Effect on chambers

Ro

Compare with previous

Doppler Echocardiography

- **Pressure Gradient**
  - Simplified Bernoulli equation: $4V^2$
- **Effective Orifice Area**
  - Continuity equation: EOA = stroke volume / VTI_{PrV}
  - Better index of valve function than gradient alone
- **Dimensionless Index (DVI)** = ratio of velocity proximal to the valve, to the velocity through the valve

Doppler Echocardiography

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  - Simplified Bernoulli equation: $4V^2$
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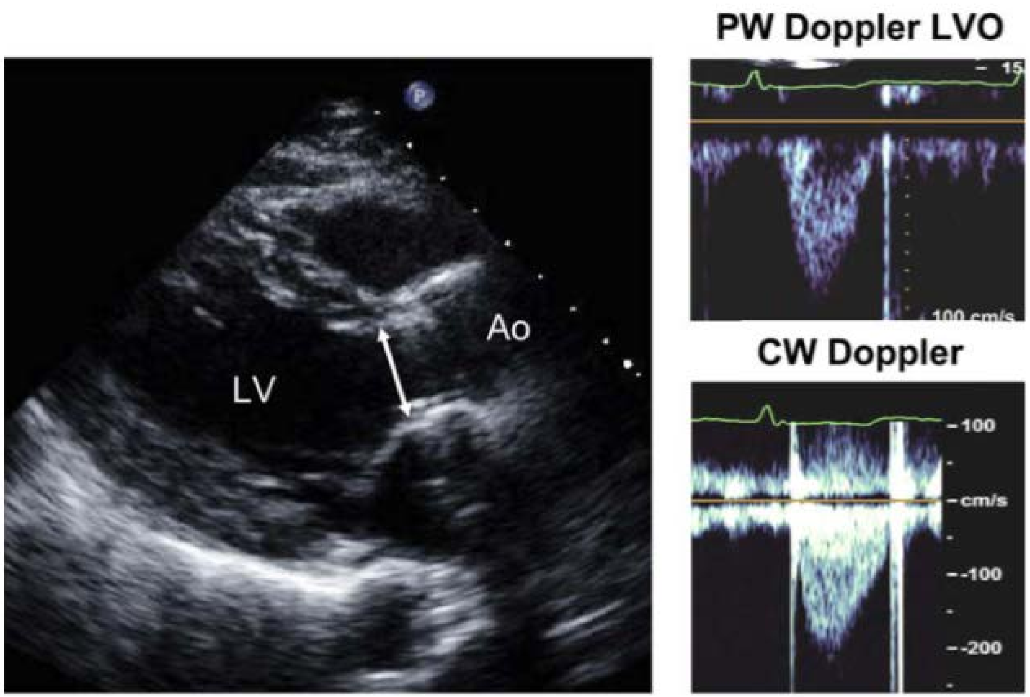
Effective Orifice Area

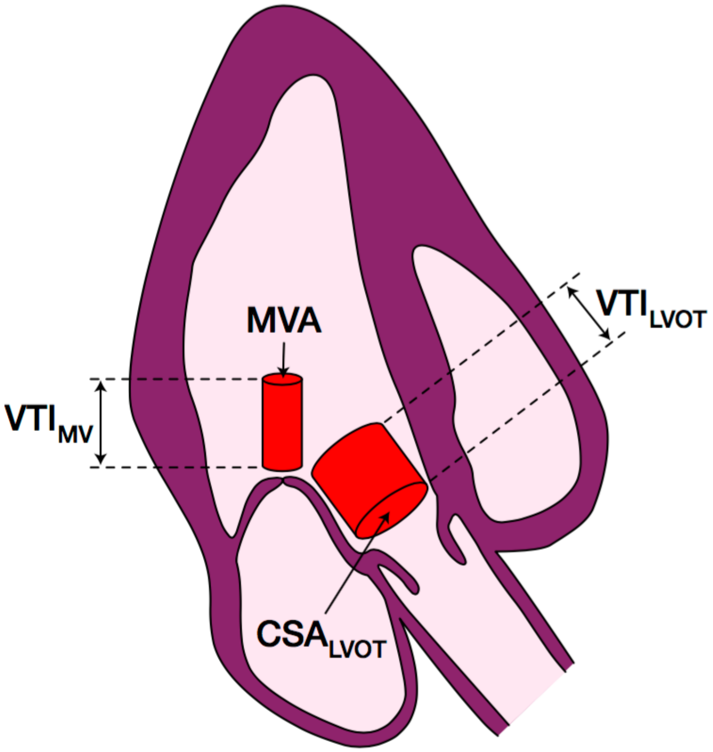


$$\text{Effective Orifice Area} = \frac{CSA_{LVO} \times VTI_{LVO}}{VTI_{JET}}$$

Pressure Half Time

- **not appropriate** to use the pressure half-time formula (220/pressure half-time) to estimate orifice area in prosthetic valves.
- valid only for **moderate or severe stenoses** (< 1.5 cm^2).
- For larger valve areas, PHT reflects *atrial* and *LV compliance* characteristics and *loading conditions* and has no relation to valve area.

Mitral Valve Continuity Equation



(Equation 12.8)

$$MVA = \frac{CSA_{LVOT} \times VTI_{LVOT}}{VTI_{MV}}$$

where MVA = mitral valve area (cm^2)

CSA_{LVOT} = cross-sectional area of left ventricular outflow tract (cm^2)

VTI_{LVOT} = velocity time integral through the left ventricular outflow tract (cm)

VTI_{MV} = velocity time integral across the mitral valve (cm)

Doppler Echocardiography

- **Pressure Gradient**
  - Simplified Bernoulli equation: $4V^2$
- **Effective Orifice Area**
  - Continuity equation: EOA = stroke volume / VTI_{PrV}
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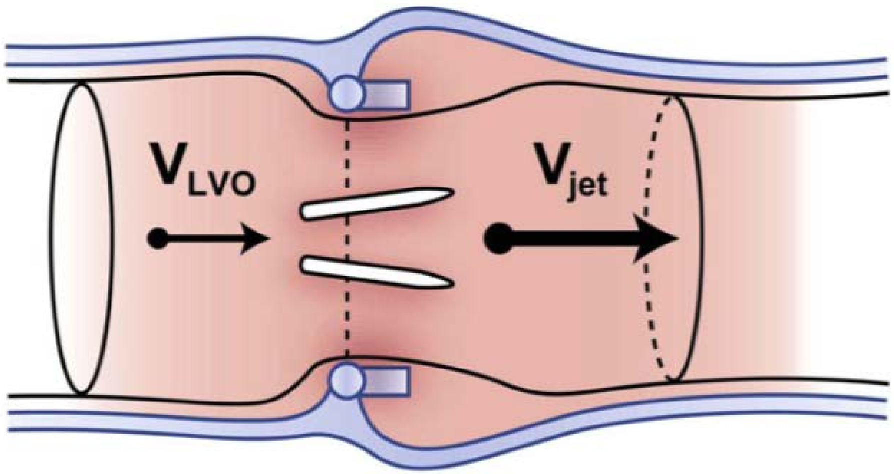
Dimensionless Valve Index (DVI)



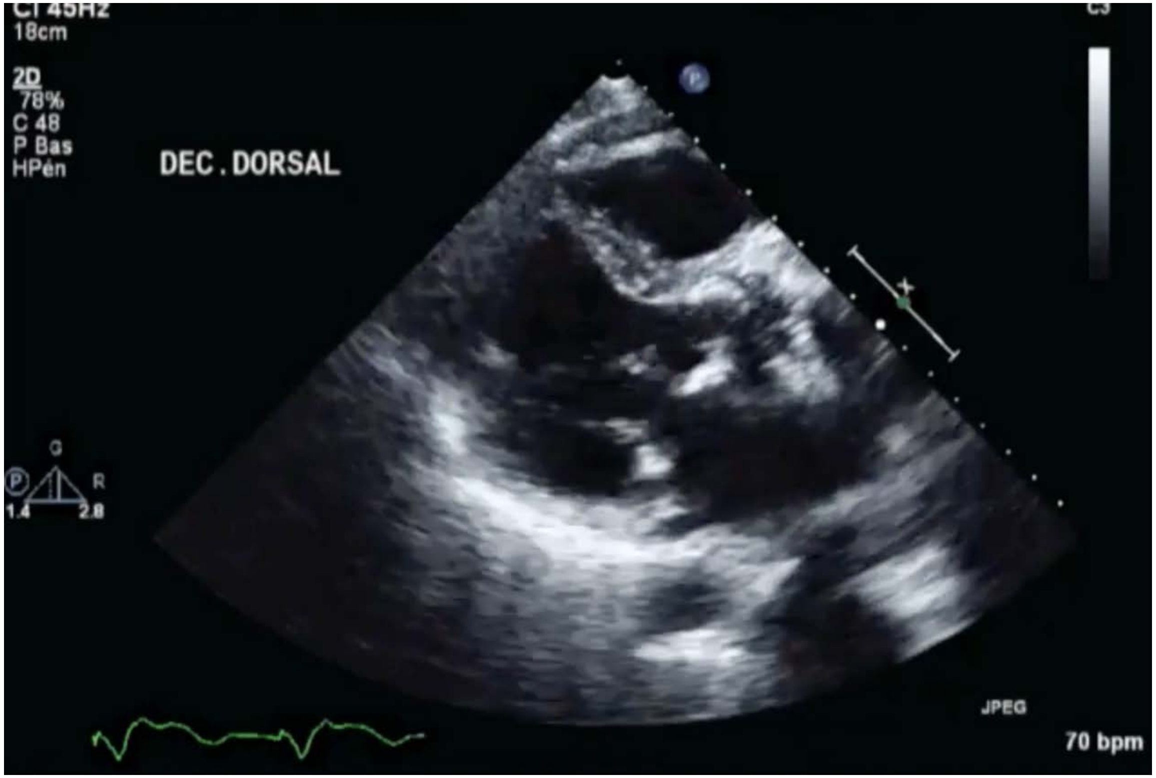
$$\text{Doppler Velocity Index} = \frac{\text{Velocity}_{LVO}}{\text{Velocity}_{jet}}$$

Figure 9 Schematic representation of the concept of the DVI. Velocity across the prosthesis is accelerated through the jet from the LVO tract. DVI is the ratio velocity in the LVO (V_{lvo}) to that of the jet (V_{jet}).

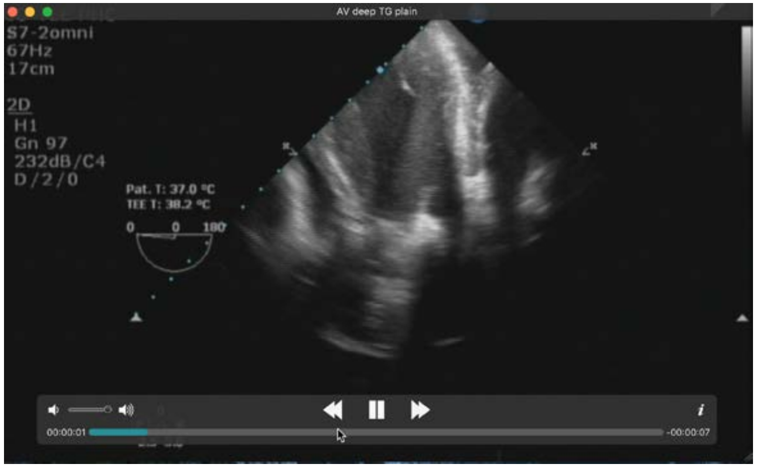
Early and Late Complications of Prosthetic Valves

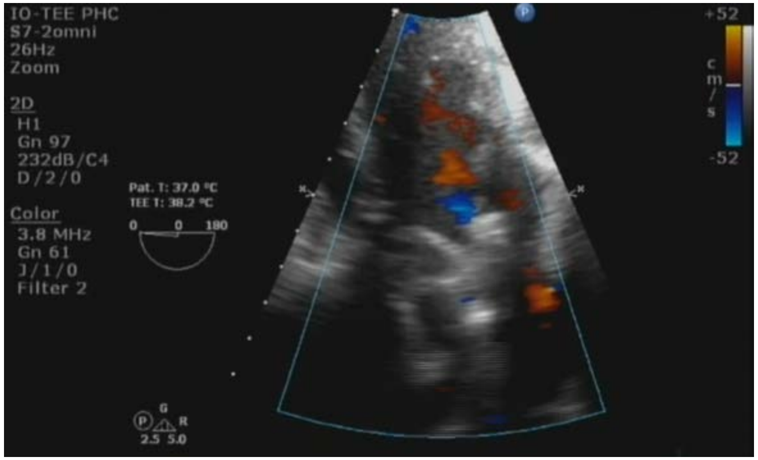
PPM
Geometric mismatch
Dehiscence
Primary failure
Thrombosis and thromboembolism
Pannus formation
Pseudoaneurysm formation
Endocarditis
Hemolysis

Normal Mechanical Prosthesis at Aortic Position



Normal Bi-leaflet Mechanical Aortic Valve (TEE)





Stented Bioprosthetic Mitral Valve

Prosthetic Valve Obstruction

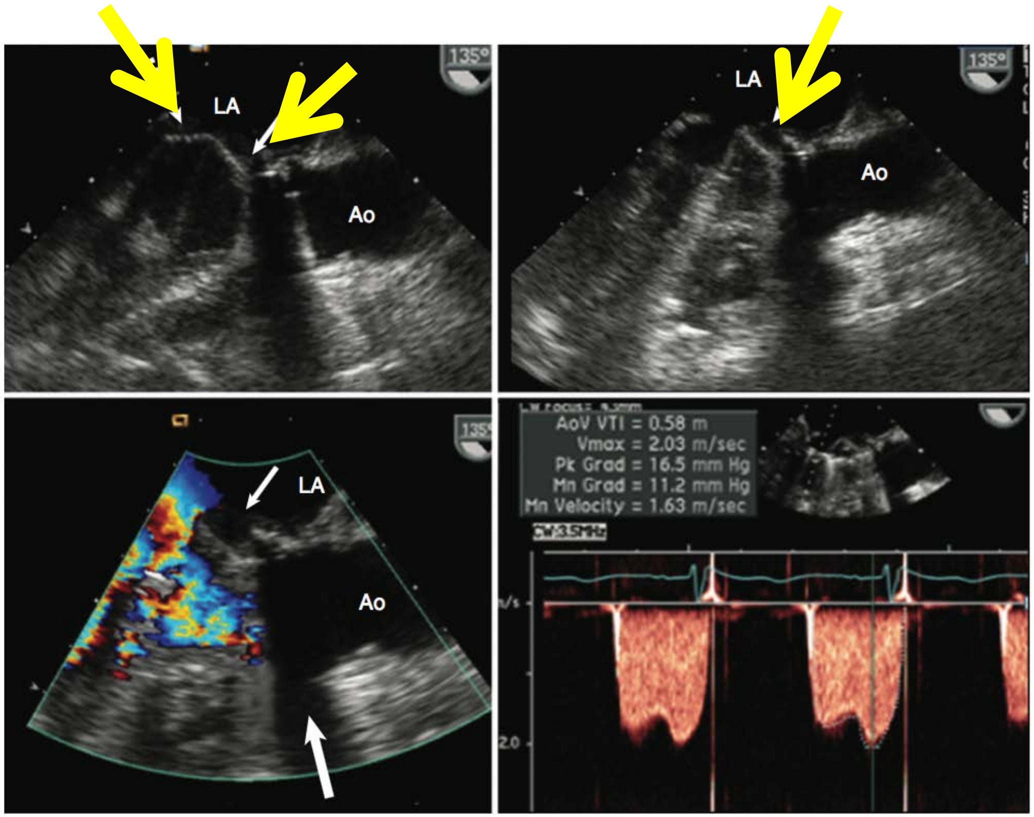
- Mechanical Valves: Thrombus or Pannus
- Bioprosthetic: structural valve degeneration (SVD)
  - (Abnormal leaflet morphology / mobility)
  - Increased gradient for valve subtype and size
  - Decreased EOA and DVI
  - Significant deviation from baseline study

#Importance of "finger printing**" iEOA and DVI typically unchanged** compared to baseline

Prosthetic Valve Obstruction: Thrombus

Systole:
both leaflets doesn't close fully

Diastole:
left disc opens fully, right disc immobilized

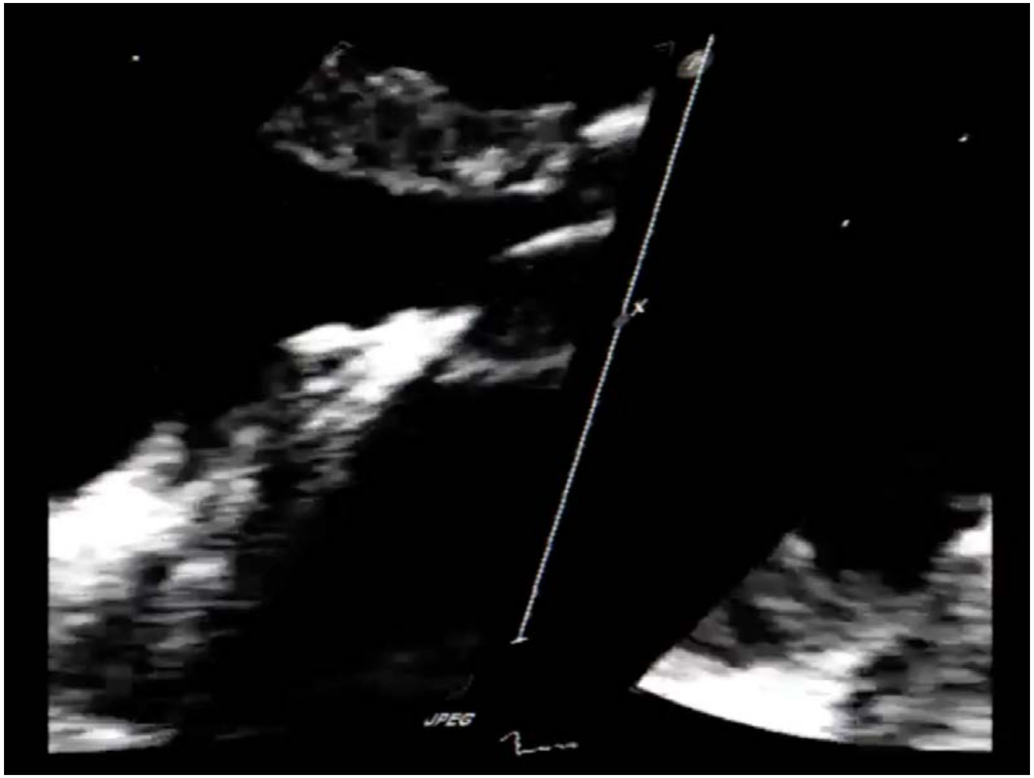


High velocity flow through single orifice

Elevated transmitral gradient = 11.2 mmHg

Abnormal Mechanical Valve at Mitral Position

Decreased occluder motion and thrombus at the LV side of the prosthesis



Pre- & post-thrombolysis of SJM mitral valve

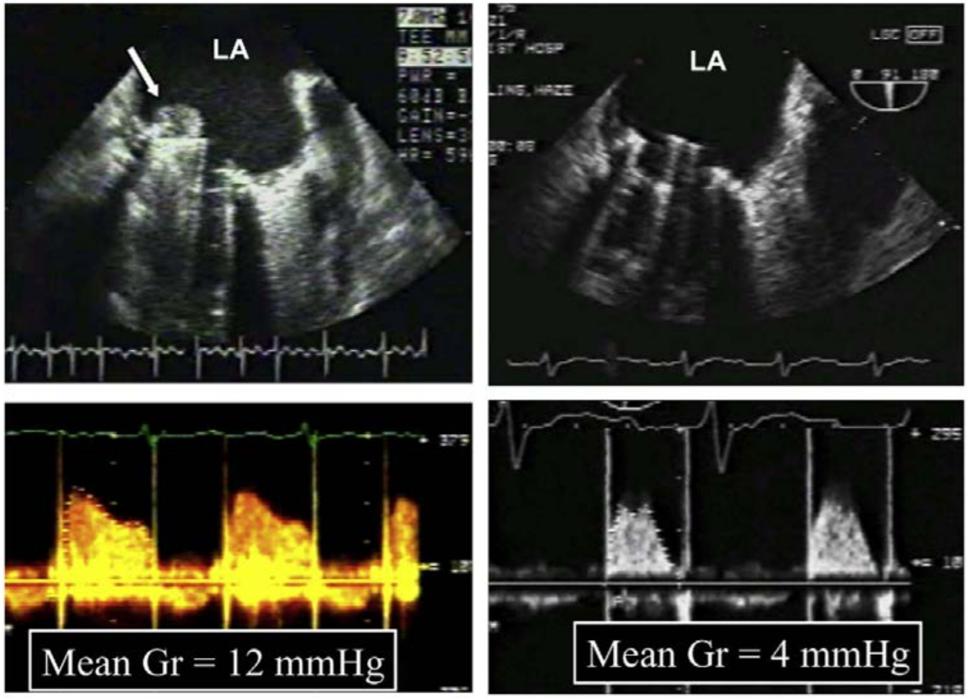
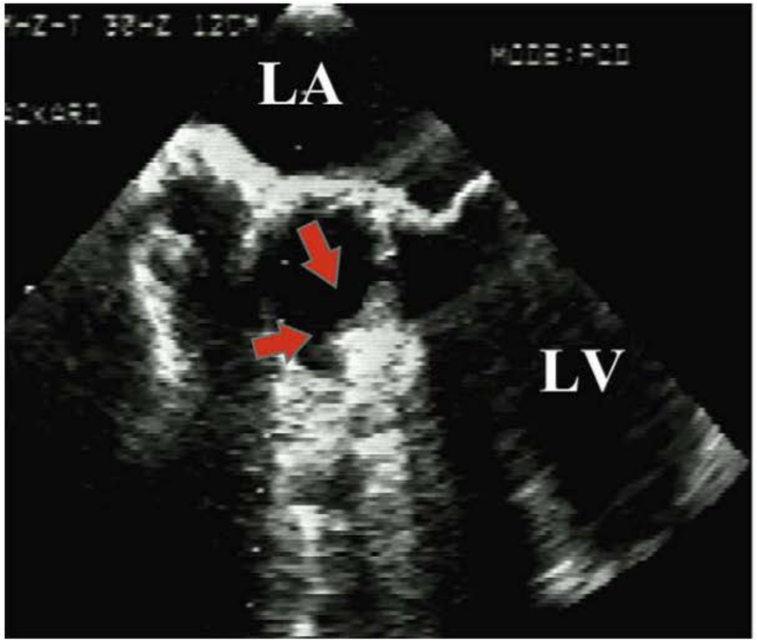
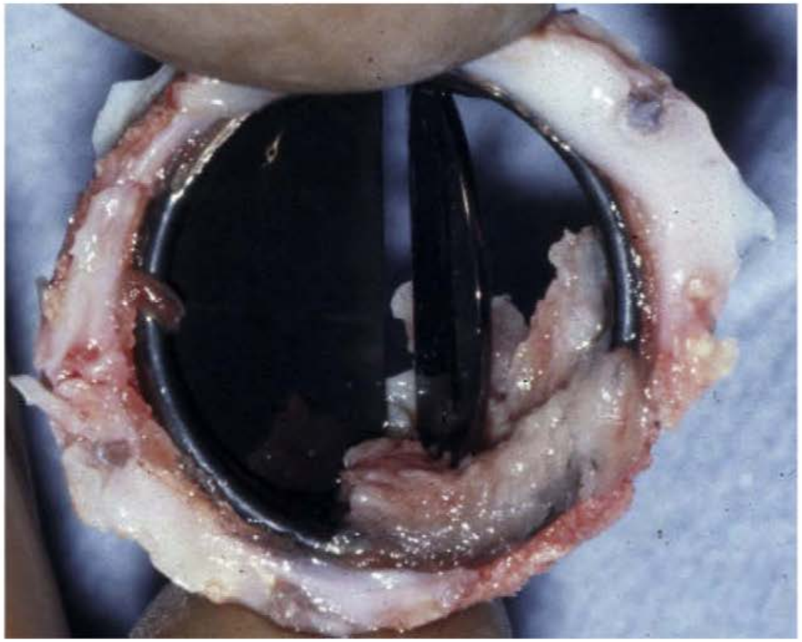


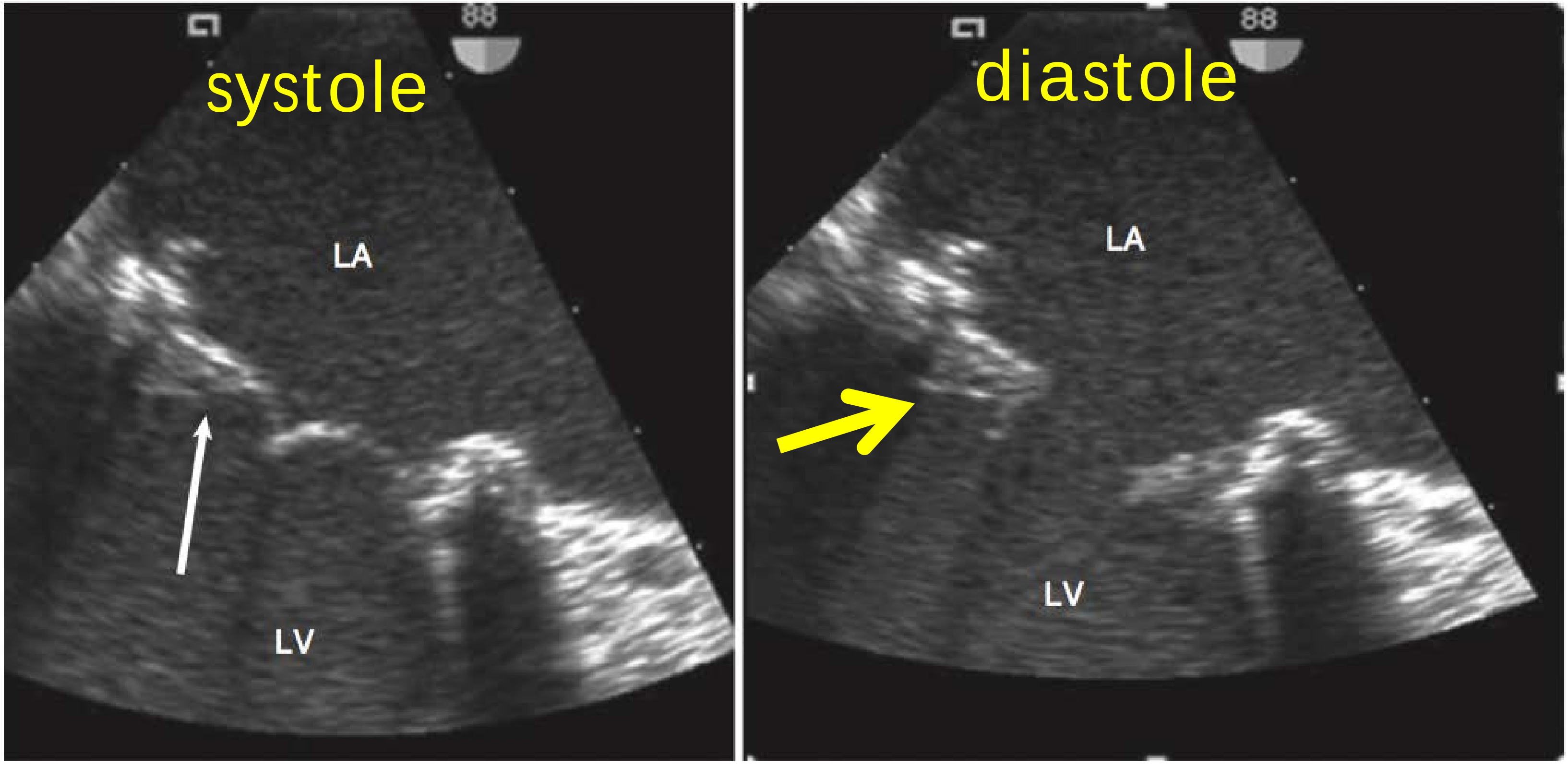
Figure 6 Prosthetic St Jude Medical valve thrombosis in the mitral position *(arrow)* obstructing and immobilizing one of the leaflets of the valve. After thrombolysis, leaflet mobility is restored, and the mean gradient (Gr) is significantly decreased. *LA*, Left atrium.

Pannus Formation in Mechanical Valve





Pannus Ingrowth Mitral Bioprosthesis

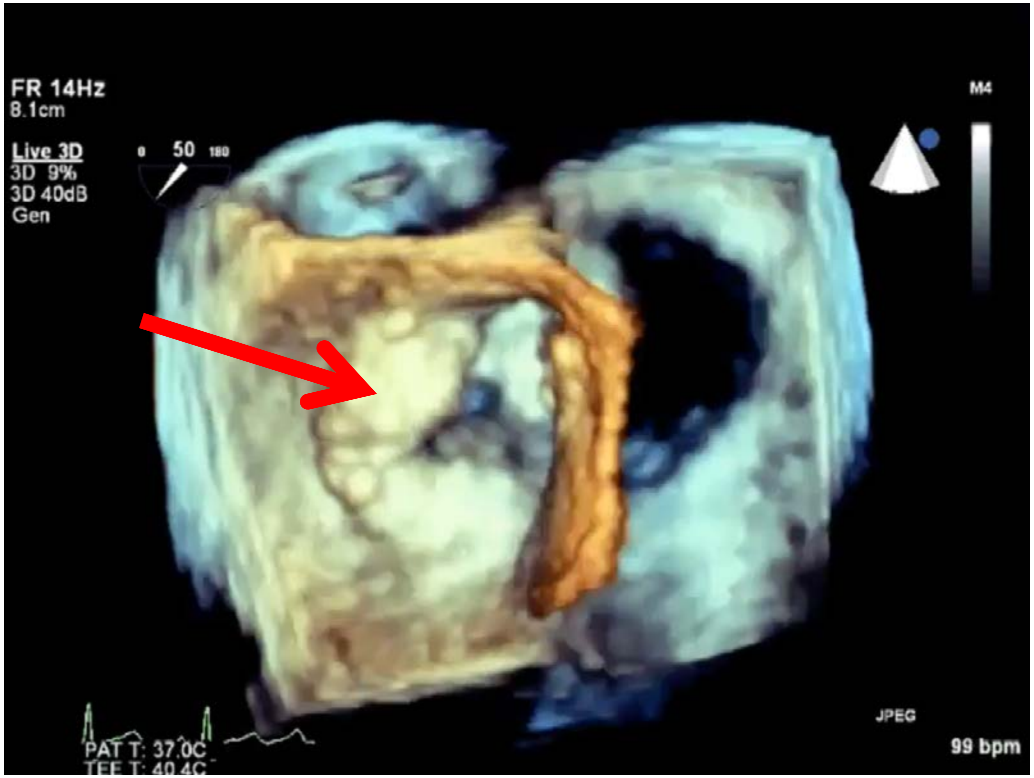


Pannus Bioprosthetic Valve

Elevated gradients across a bioprosthetic mitral valve

Pannus by TEE (echogenic area on the atrial side of the prosthesis)

Pannus formation



Evaluation of Prosthetic Valves by Location

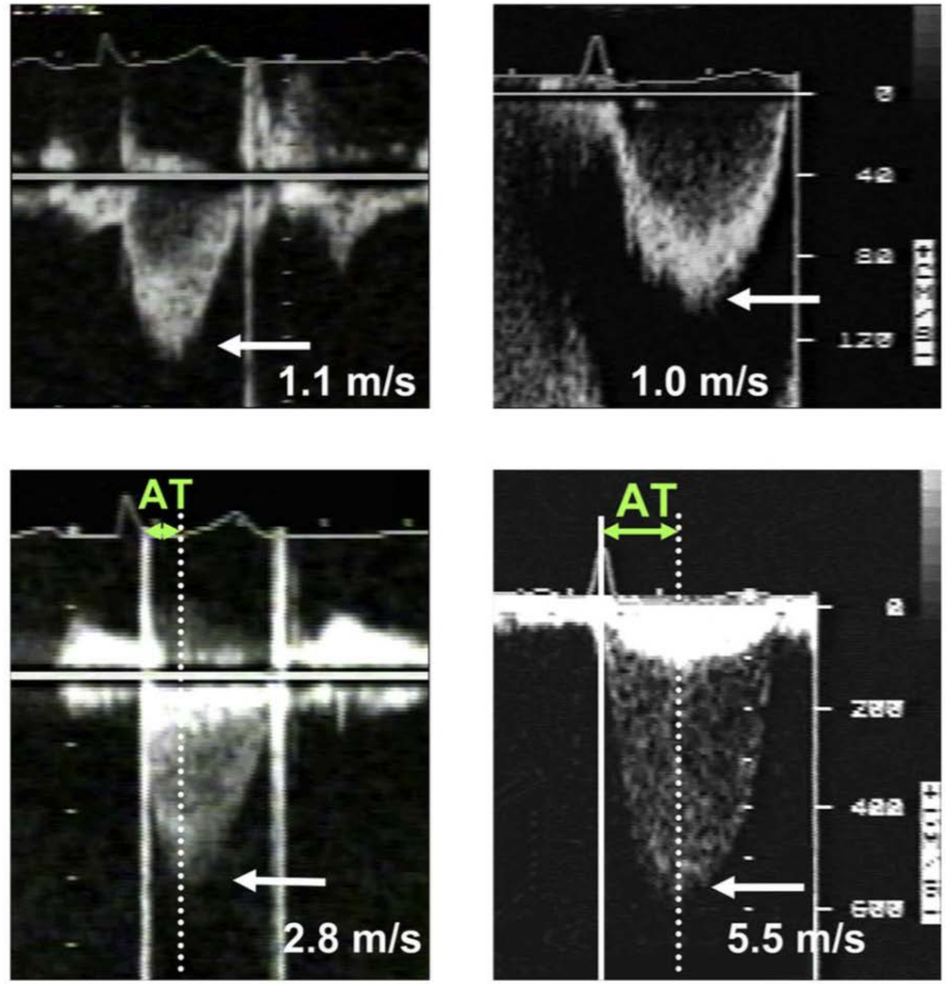
Table 4 Doppler echocardiographic evaluation of prosthetic aortic valves

	Parameter
Doppler echocardiography of the valve	Peak velocity/gradient Mean gradient Contour of the jet velocity; AT DVI EOA Presence, location, and severity of regurgitation
Pertinent cardiac chambers	LV size, function, and hypertrophy

Normal | **Obstructed**

Pulsed Doppler LVO

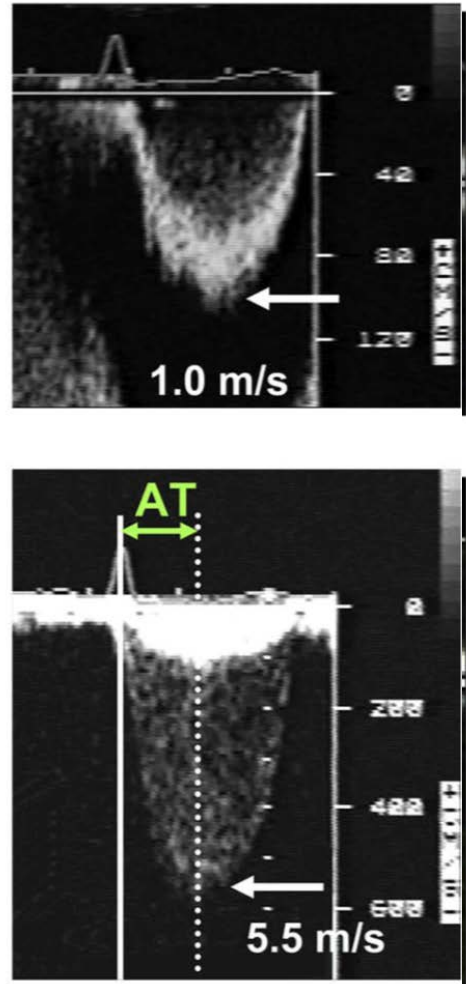
CW Doppler Prosthetic AV



Normal	Obstructed
MG = 22 mmHg	MG = 80 mmHg
DVI = 0.4	DVI = 0.18
AT = 75 ms	AT = 180 ms

Doppler parameters of p enosis

Obstructed



MG = 80 mmHg
DVI = 0.18
AT = 180 ms

Table 5 Doppler parameters of prosthetic aortic valve function in m lves*

Parameter	Normal	Suggests significant stenosis
Peak velocity (m/s)†	<3	>4
Mean gradient (mm Hg)†	<20	>35
DVI	≥0.30	<0.25
EOA (cm^2)	>1.2	<0.8
Contour of the jet velocity through the PrAV	Triangular, early peaking	Rounded, symmetrical contour
AT (ms)	<80	>100

PrAV, Prosthetic aortic valve.
*In conditions of normal or near normal stroke volume (50-70 mL) through the
†These parameters are more affected by flow, including concomitant AR.

Inday – 41 year old female

Ht 149 cm Wt 53 kg **BSA 1.46 m2**

Concentric LVH LVMI = 119 gm/2, RWT = 0.53, LVEF 74%

Aortic root = 2.8 cm
LVOT dia = 2.1 cm
LVOT VTI = 26.7
Ao VTI = 98.1
DVI = 0.27
EOA = 0.94 cm2
iEOA = 0.64
MVG = 42 mmHg
PIG = 89 mmg
SPAP = 33 mmHg

Prosthesis Patient Mismatch

- No detectable structural abnormality of the PV leaflets / occluders
- Normal EOA and DVI for subtype
- iEOA $\leq$ 0.85 **(0.64)**

Consequences of PPM

- Worse hemodynamics
- Less regression of LVH (and pulmonary HPN)
- Worse functional class, exercise capacity, and quality of life
- More cardiac events
- Lower survival

Indexed EOA is the only parameter shown to have any correlation with post-operative gradients &/or outcomes in **prosthetic valve mismatch**

Determinants of Mismatch

- larger BSA - **higher cardiac output requirements**
- older age
- smaller prosthesis size (≤ size19)
- valvular stenosis as the predominant lesion before the operation

Prevention of PPM

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STEP 1:
Calculate BSA = 1.64

STEP 2:
Determine minimal projected EOA

BSA x 0.85
1.64 x 0.85 = 1.394

STEP 3:
Choose prosthesis using reference values for EOA

Table 1. Three Easy Steps to Avoid Prosthesis–Patient Mismatch

Step I: Calculate the patient's body surface (BSA) area using the rmula:

$$BSA = ([Weight_{kg}]^{0.425} \times [height_{cm}]^{0.725}) \times 0.007184$$

Step II: Determine the minimal requirement for prosthetic valve effective orifice area (EOA) to avoid prosthesis–patient mismatch.

Patient BSA (m^2)	Minimal Valve EOA (cm^2) for Indexed EOA >0.85 cm^2/m^2 (Ideal)	Minimal Valve EOA (cm^2) for Indexed EOA >0.80 cm^2/m^2	Minimal Valve EOA (cm^2) for Indexed EOA >0.75 cm^2/m^2
1.30	1.11	1.04	0.98
1.35	1.15	1.08	1.01
1.40	1.20	1.12	1.05
1.45	1.23	1.16	1.09
1.50	1.28	1.20	1.13
1.55	1.32	1.24	1.16
1.60	1.36	1.28	1.20
1.65	1.40	1.32	1.24
1.70	1.45	1.36	1.28
1.75	1.49	1.40	1.31
1.80	1.53	1.44	1.35
1.85	1.57	1.48	1.39
1.90	1.62	1.52	1.43
1.95	1.66	1.56	1.46
2.00	1.70	1.60	1.50
2.05	1.74	1.64	1.54
2.10	1.79	1.68	1.58
2.15	1.83	1.72	1.61
2.20	1.87	1.76	1.65
2.25	1.91	1.80	1.69
2.30	1.96	1.84	1.73
2.35	2.00	1.88	1.76
2.40	2.04	1.92	1.80
2.45	2.08	1.96	1.84
2.50	2.13	2.00	1.88

Step III: Choose a prosthesis using reference values for EOA of different types and sizes of prostheses (see Table 2).

	EOAi by Prosthesis size (mm)					
Prosthesis size (mm)	**19**	**21**	**23**	**25**	**27**	**29**
Average EOA (cm^2)	1.1	1.3	1.5	1.8	2.3	2.7
BSA (m^2)						
0.6	1.83	2.17	2.50	3.00	3.83	4.50
0.7	1.57	1.86	2.14	2.57	3.29	3.86
0.8	1.38	1.63	1.88	2.25	2.88	3.38
0.9	1.22	1.44	1.67	2.00	2.56	3.00
1	1.10	1.30	1.50	1.80	2.30	2.70
1.1	1.00	1.18	1.36	1.64	2.09	2.45
1.2	0.92	1.08	1.25	1.50	1.92	2.25
1.3	0.85	1.00	1.15	1.38	1.77	2.08
1.4	0.79	0.93	1.07	1.29	1.64	1.93
1.5	0.73	0.87	1.00	1.20	1.53	1.80
1.6	0.49	0.88	0.88	0.88	0.88	1.69
1.7	0.65	0.76	0.88	1.06	1.35	1.59
1.8	0.61	0.72	0.83	1.00	1.28	1.50
1.9	0.58	0.68	0.79	0.95	1.21	1.42
2	0.55	0.65	0.75	0.90	1.15	1.35
2.1	0.52	0.62	0.71	0.86	1.10	1.29
2.2	0.50	0.59	0.68	0.82	1.05	1.23
2.3	0.48	0.57	0.65	0.78	1.00	1.17
2.4	0.46	0.54	0.63	0.75	0.96	1.13
2.5	0.44	0.52	0.60	0.72	0.92	1.08

STEP 3:
Choose prosthesis using reference values for EOA
1.4

Table 2. Normal Effective Orifice Areas for the Most Currently Used Prosthetic Valves

Prosthetic Valve Size (mm)	19	21	23	25	27	29	Reference no.
Stented Bioprosthetic valves							
Medtronic Intact	0.85	1.02 ± 0.10	1.27 ± 0.11	1.40 ± 0.20	1.66 ± 0.16	2.04 ± 0.23	(2)
Medtronic Mosaic	—	1.22 ± 0.27	1.38 ± 0.23	1.65 ± 0.39	1.59 ± 0.33	1.65 ± 0.37	(95)
Hancock II	—	1.18 ± 0.11	1.33 ± 0.16	1.46 ± 0.15	1.55 ± 0.18	1.60 ± 0.15	(3)
Carpentier-Edwards SAV 2650	—	1.16 ± 0.14	—	—	—	—	(96)
Carpentier-Edwards Pericardial 2900	1.10	1.30	1.50	1.80	1.60	—	(97)
Stentless bioprosthetic valves							
Medtronic Freestyle	1.15	1.35 ± 0.21	1.48 ± 0.33	2.00 ± 0.39	2.32 ± 0.48	—	(39)
	1.29 ± 0.19	1.46 ± 0.32	1.79 ± 0.33	2.34 ± 0.69	2.67 ± 0.75	—	(98)
St. Jude Medical Toronto SPV	—	1.30	1.50	1.70	2.00	2.50	(SJM†)
	—		1.49 ± 0.45	1.70 ± 0.78	2.12 ± 0.66	2.70 ± 1.03	(99)
Prima Edwards	0.80	1.10	1.50	1.80	2.30	2.80	(100)
Mechanical valves							
Medtronic Hall	1.19 ± 0.21*	1.34 ± 0.15	—	—	—	—	(96)
Carbomedics Standard	1.00 ± 0.40	1.54 ± 0.31	1.63 ± 0.30	1.98 ± 0.41	2.41 ± 0.46	2.63 ± 0.38	(93)
	1.11 ± 0.13	1.52 ± 0.22	1.84 ± 0.25	2.12 ± 0.31	2.65 ± 0.21	—	(14)
St. Jude Medical Standard	—	1.73 ± 0.38	2.13 ± 0.61	—	—	—	(101)
	—	1.76 ± 0.47	2.11 ± 0.63	—	—	—	(26)
	1.04 ± 0.19	1.38 ± 0.22	1.52 ± 0.26	2.08 ± 0.41	2.65 ± 0.58	3.23 ± 0.30	(13)
St. Jude Medical Hemodynamic Plus	1.30 ± 0.30	—	—	—	—	—	(102)
	—	2.01 ± 0.17	—	—	—	—	(101)
	—	2.15 ± 0.29	—	—	—	—	(26)

*The label valve size of this valve is 20 mm. †Data provided by St. Jude Medical.

Effective orifice areas are expressed as the mean value ±SD cm^2. The effective orifice areas were measured by Doppler echocardiography using the continuity equation in patients with normally functioning prostheses. Some data appear conflicting or are based on limited series and may have to be revised as more data become available.

Evaluation of Prosthetic Valve by Location

Table 7 Echocardiographic and Doppler parameters in evaluation of prosthetic mitral valve function (stenosis or regurgitation)

Doppler echocardiography of the valve	Peak early velocity
	Mean gradient
	Heart rate at the time of Doppler
	Pressure half-time
	DVI*: VTI_{PrMV}/VTI_{LVO}
	EOA*
	Presence, location, and severity of regurgitation†
Other pertinent echocardiographic and Doppler parameters	LV size and function
	LA size‡
	RV size and function
	Estimation of pulmonary artery pressure

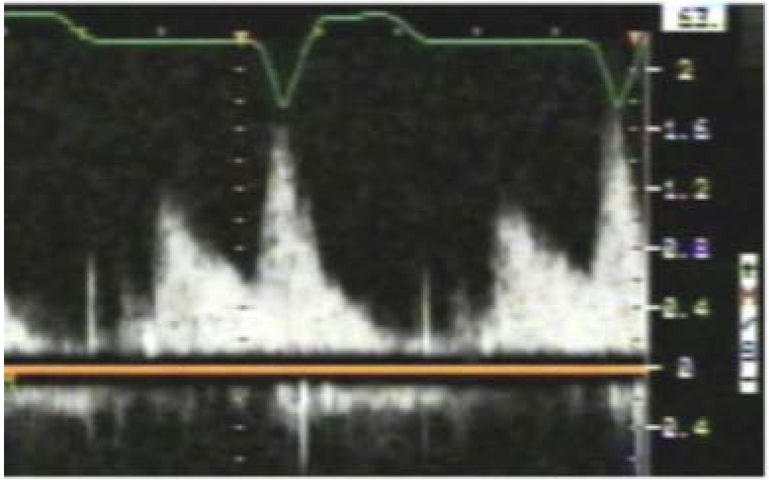
Doppler Evaluation of Mitral Stenosis

Table 8 Doppler parameters of prosthetic mitral valve function

	Normal*	Possible stenosis‡	Suggests significant stenosis* ‡
Peak velocity (m/s)† §	<1.9	1.9-2.5	≥2.5
Mean gradient (mm Hg)† §	≤5	6-10	>10
VTI_{PrMV}/VTI_{LVO}† §	<2.2	2.2-2.5	>2.5
EOA (cm^2)	≥2.0	1-2	<1
PHT (ms)	<130	130-200	>200

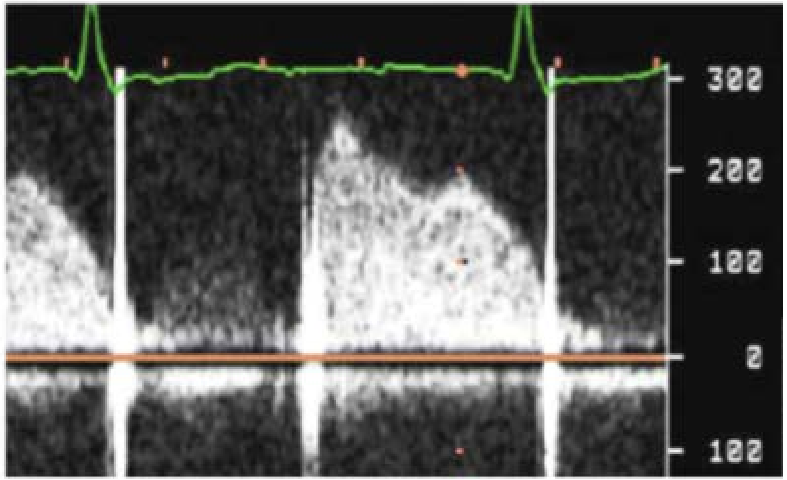
Doppler Evaluation of Mitral Prosthesis

Normal



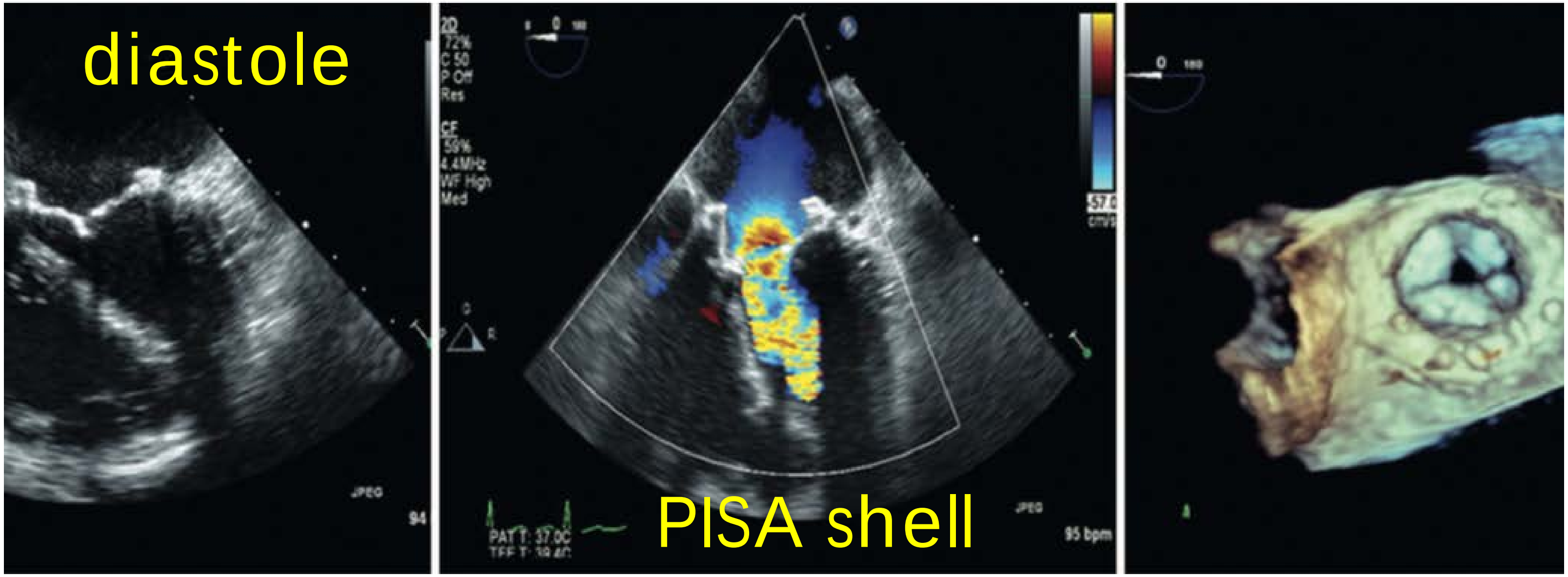
Peak E = 1.1 m/s
Mean G = 4 mmHg
PHT = 123 ms

Obstructed



Peak E = 2.5 m/s
Mean G = 15 mmHg
PHT = 170 ms

Degenerated Mitral Bioprosthesis

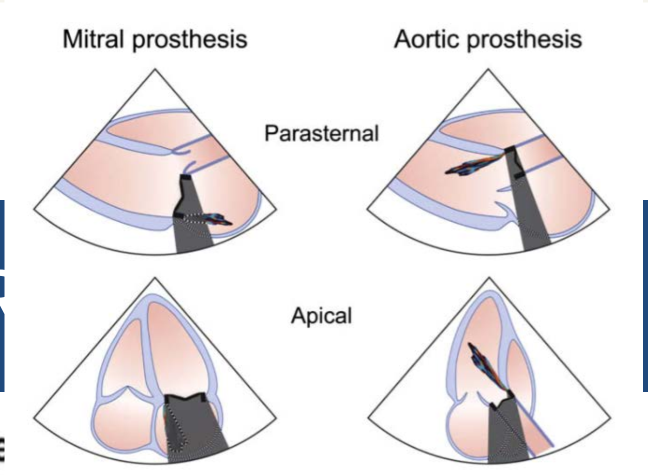


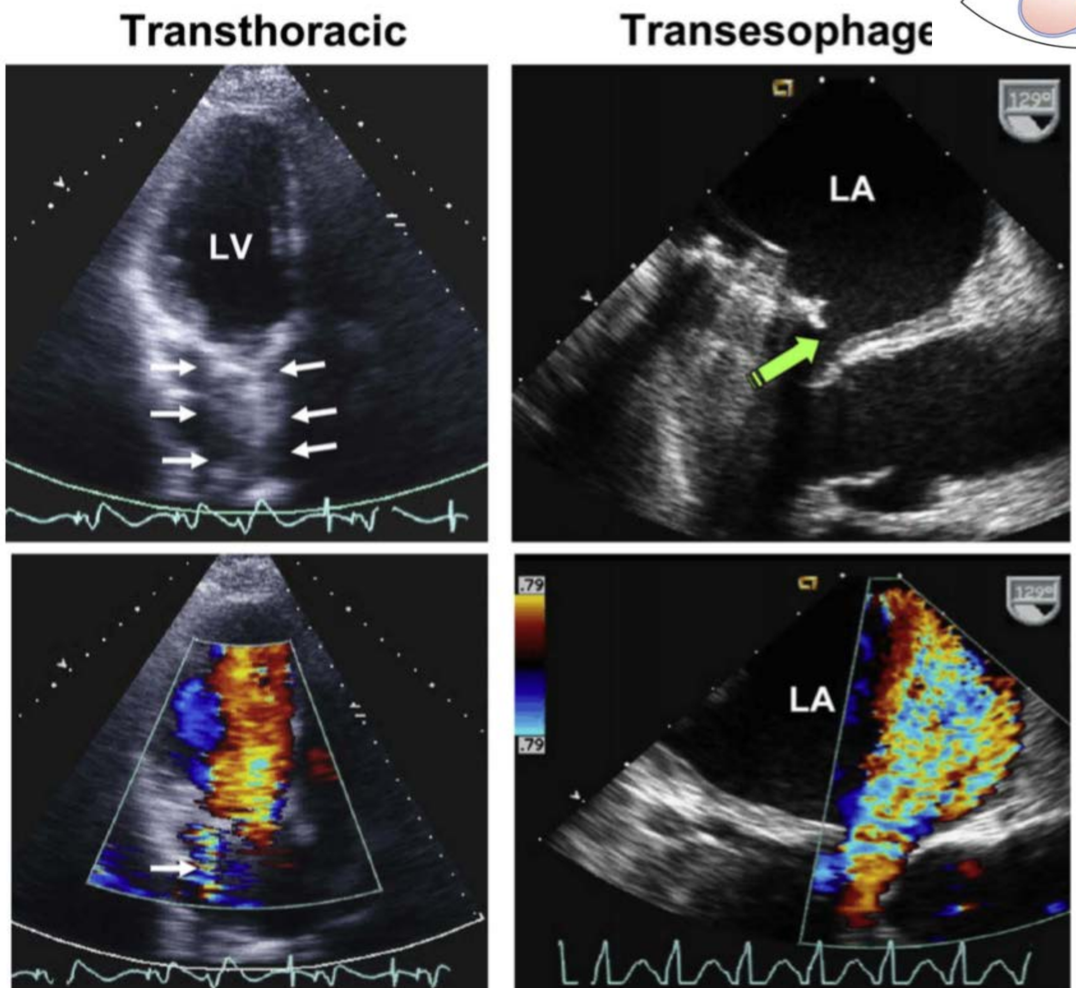
Physiologic vs Pathologic Regurgitation

- **Washing jets** to prevent thrombus formation
- 10-15%
- Jets low in momentum
  - homogeneous in color,
  - aliasing mostly confined to the base of the jet.

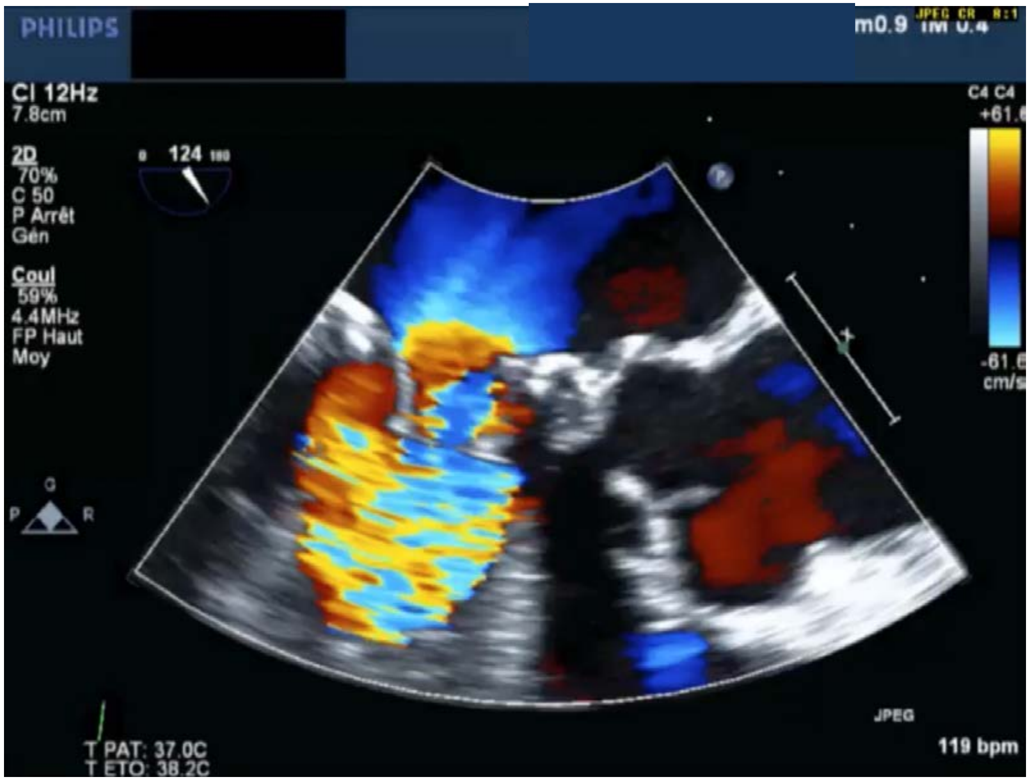
- **Central**
- **Paravalvular**

Severe Paravalvular MR

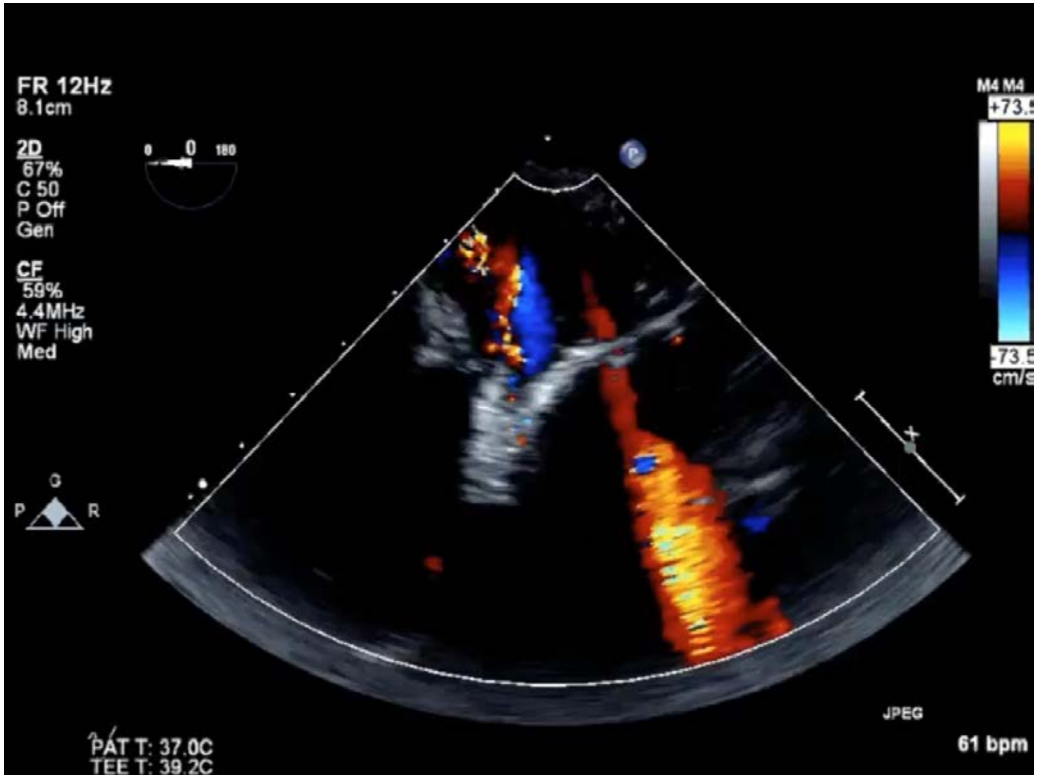




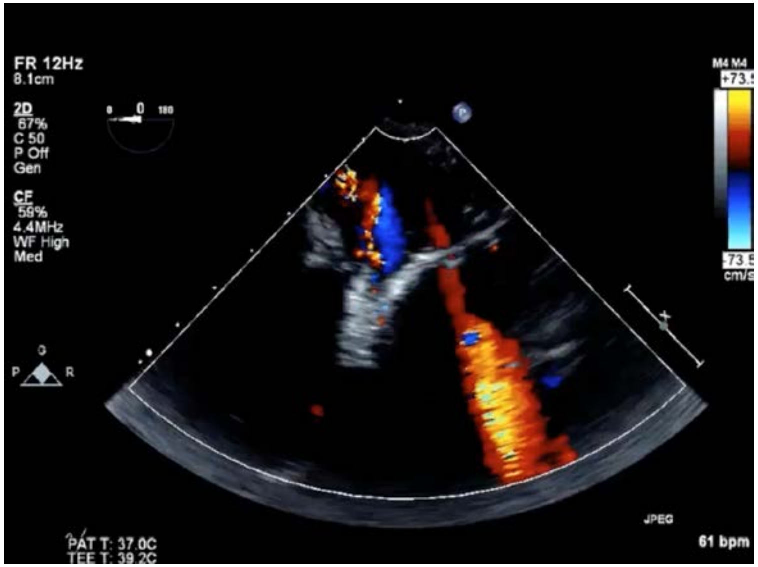
Mild central MR across a bioprosthetic



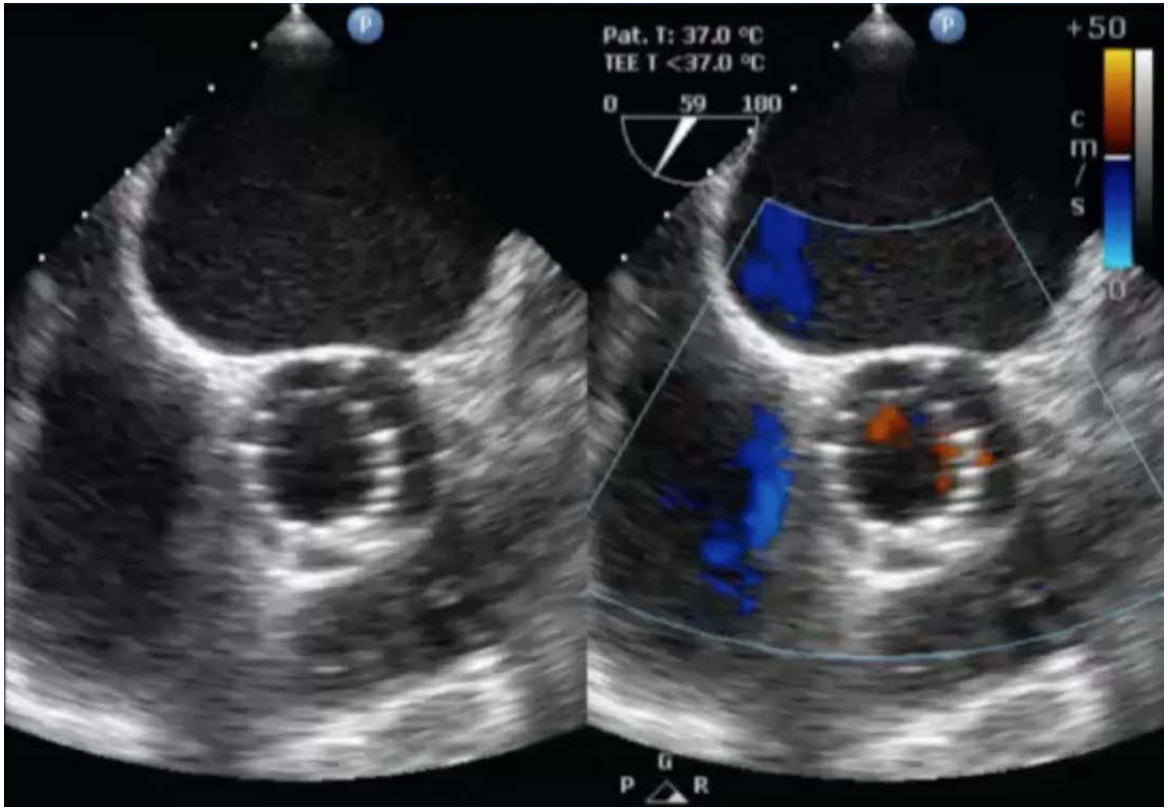
Large paravalvular leak



Dehiscence

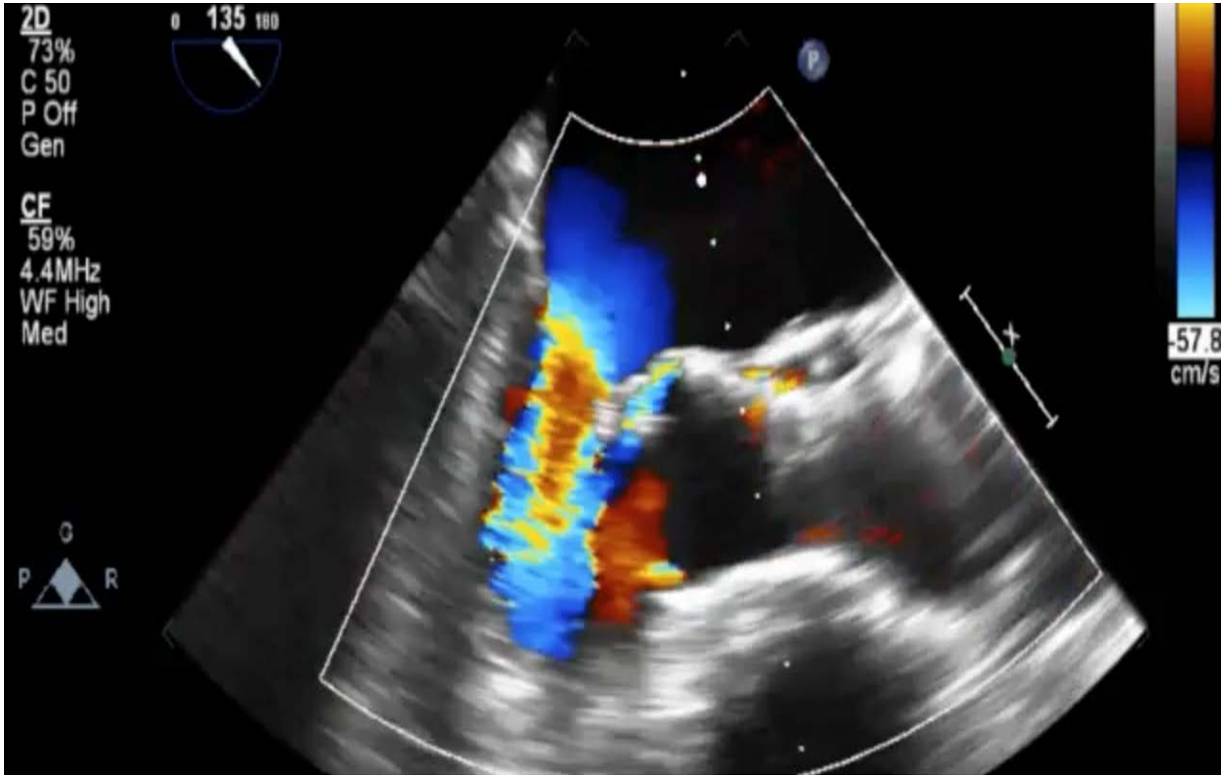

FR 12Hz
8.1cm
2D
67%
C 50
P Off
Gen
CF
59%
4.4MHz
WF High
Med
JPEG
61 bpm
PAT T: 37.0C
TEE T: 39.2C

Paravalvular Leak

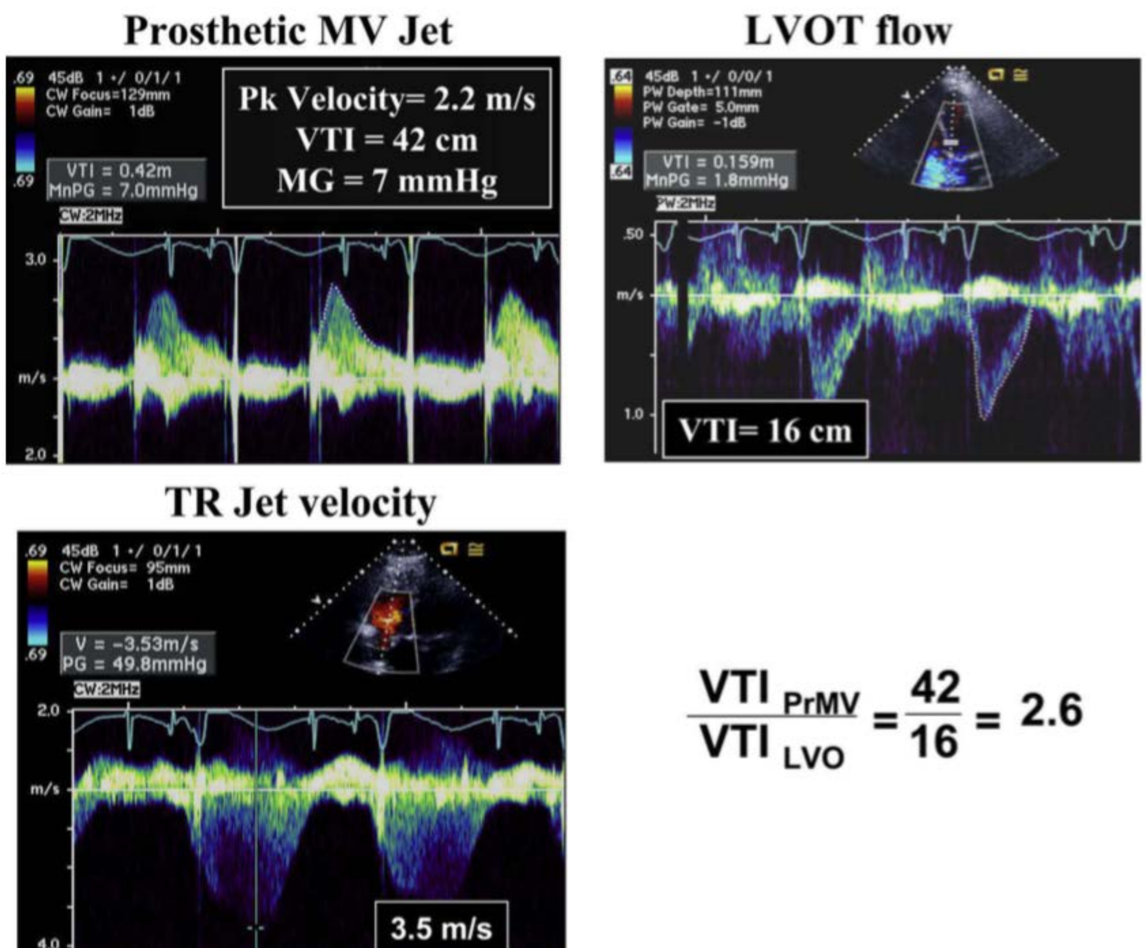


Pat. T: 37.0 °C
TEE T <37.0 °C
0
59
180
+50
cm/s
G
P
R

Periprosthetic Leak (CoreValve)



Significant Mechanical Mitral Regurgitation



$$\frac{VTI_{PrMV}}{VTI_{LVO}} = \frac{42}{16} = 2.6$$

Figure 13 Transthoracic Doppler echocardiographic clues for significant mechanical MR. These recordings are for the same patient

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

Finding	Sensitivity	Specificity	Comments
Peak mitral velocity ≥1.9 m/s*	90%	89%	Also consider high flow, PPM
$VTI_{PrMV}/VTI_{LVO} \geq 2.5$*	89%	91%	Measurement errors increase in atrial fibrillation due to difficulty in matching cardiac cycles; also consider PPM
Mean gradient ≥ 5 mmHg*	90%	70%	At physiologic heart rates; also consider high flow, PPM
Maximal TR jet velocity > 3 m/s*	80%	71%	Consider residual postoperative pulmonary hypertension or other causes
LV stroke volume derived by 2D or 3D imaging is >30% higher than systemic stroke volume by Doppler	Moderate sensitivity	Specific	Validation lacking; significant MR is suspected when LV function is normal or hyperdynamic and VTI_{LVO} is <16 cm
Systolic flow convergence seen in the left ventricle toward the prosthesis	Low sensitivity	Specific	Validation lacking; technically challenging to detect readily

Severity of Prosthetic Aortic Valve Regurgitation

Table 6 Parameters for evaluation of the severity of prosthetic aortic valve regurgitation

Parameter	Mild	Moderate	Severe
Valve structure and motion			
Mechanical or bioprosthetic	Usually normal	Abnormal†	Abnormal†
Structural parameters			
LV size	Normal‡	Normal or mildly dilated‡	Dilated‡
Doppler parameters (qualitative or semiquantitative)			
Jet width in central jets (% LVO diameter): color*	Narrow (≤25%)	Intermediate (26%-64%)	Large (≥65%)
Jet density: CW Doppler	Incomplete or faint	Dense	Dense
Jet deceleration rate (PHT, ms): CW Doppler§	Slow (>500)	Variable (200-500)	Steep (<200)
LVO flow vs pulmonary flow: PW Doppler	Slightly increased	Intermediate	Greatly increased
Diastolic flow reversal in the descending aorta: PW Doppler	Absent or brief early diastolic	Intermediate	Prominent, holodiastolic
Doppler parameters (quantitative)			
Regurgitant volume (mL/beat)	<30	30-59	>60
Regurgitant fraction (%)	<30	30-50	>50

PHT, Pressure half-time.
*Parameter applicable to central jets and is less accurate in eccentric jets; Nyquist limit of 50 to 60 cm/s.
†Abnormal mechanical valves, for example, immobile occluder (valvular regurgitation), dehiscence or rocking (paravalvular regurgitation); abnormal biologic valves, for example, leaflet thickening or prolapse (valvular), dehiscence or rocking (paravalvular regurgitation).
‡Applies to chronic, late postoperative AR in the absence of other etiologies.
§Influenced by LV compliance.

Severity of Mitral Regurgitation

Table 10 Echocardiographic and Doppler criteria for severity of prosthetic MR using findings from TTE and TEE

Parameter	Mild	Moderate	Severe
Structural parameters			
LV size	Normal*	Normal or dilated	Usually dilated‡
Prosthetic valve‖	Usually normal	Abnormal¶	Abnormal¶
Doppler parameters			
Color flow jet area‖ #	Small, central jet (usually <4 cm^2 or <20% of LA area)	Variable	Large central jet (usually >8 cm^2 or >40% of LA area) or variable size wall-impinging jet swirling in left atrium
Flow convergence**	None or minimal	Intermediate	Large
Jet density: CW Doppler‖	Incomplete or faint	Dense	Dense
Jet contour: CW Doppler‖	Parabolic	Usually parabolic	Early peaking, triangular
Pulmonary venous flow‖	Systolic dominance§	Systolic blunting§	Systolic flow reversal†
Quantitative parameters††			
VC width (cm)‖	<0.3	0.3-0.59	≥0.6
R vol (mL/beat)	<30	30-59	≥60
RF (%)	<30	30-49	≥50
EROA (cm^2)	<0.20	0.20-0.49	≥0.50


THANK YOU FOR YOUR ATTENTION