Echocardiografie van kunstkleppen

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REVIEW

Recommendations for the imaging assessment of prosthetic heart valves: a report from the European Association of Cardiovascular Imaging endorsed by the Chinese Society of Echocardiography, the Inter-American Society of Echocardiography, and the Brazilian Department of Cardiovascular Imaging†

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Table I Types of prosthetic heart valves

- Biological
  - Stented
    - Porcine bioprosthesis
    - Pericardial bioprosthesis
  - Stentless
    - Porcine bioprosthesis
    - Pericardial bioprosthesis
    - Aortic homograft
    - Pulmonary autograft (Ross procedure)
  - Sutureless
  - Transcatheter
- Mechanical
  - Bileaflet
  - Single tilting disk
  - Caged ball

Mechanical prosthetic valves

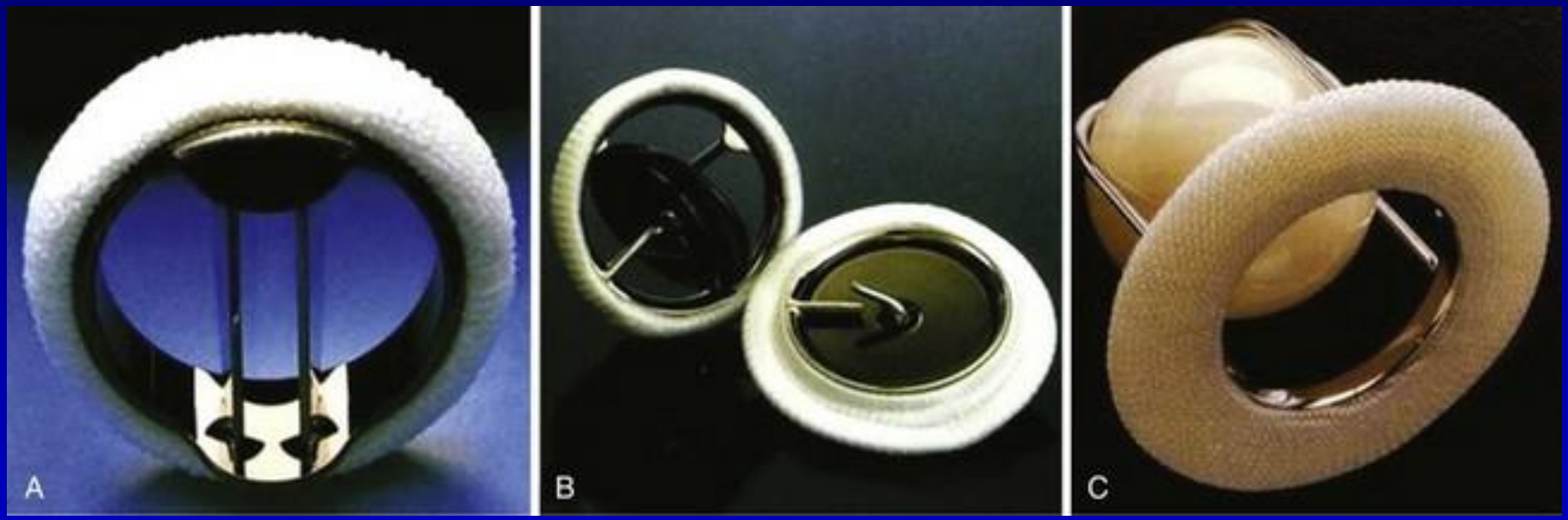
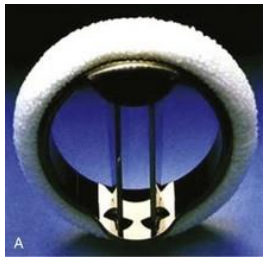


Table 3 Designs and models of mechanical replacement heart valve

Bileaflet mechanical replacement valves

- St Jude Medical: standard, HP, Masters, and Regent
- Carbomedics: standard, reduced cuff, Optiform, Orbis, and supra-annular (Top Hat) Carboseal includes a woven aortic graft
- Edwards Tekna
- Sorin Bicarbon
- Edwards Mira
- ATS
- On-X
- Medtronic Advantage
- Jyros

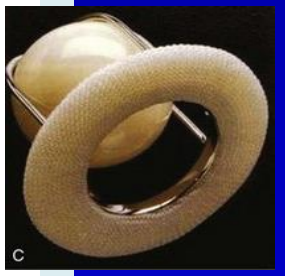


Tilting disk replacement valves

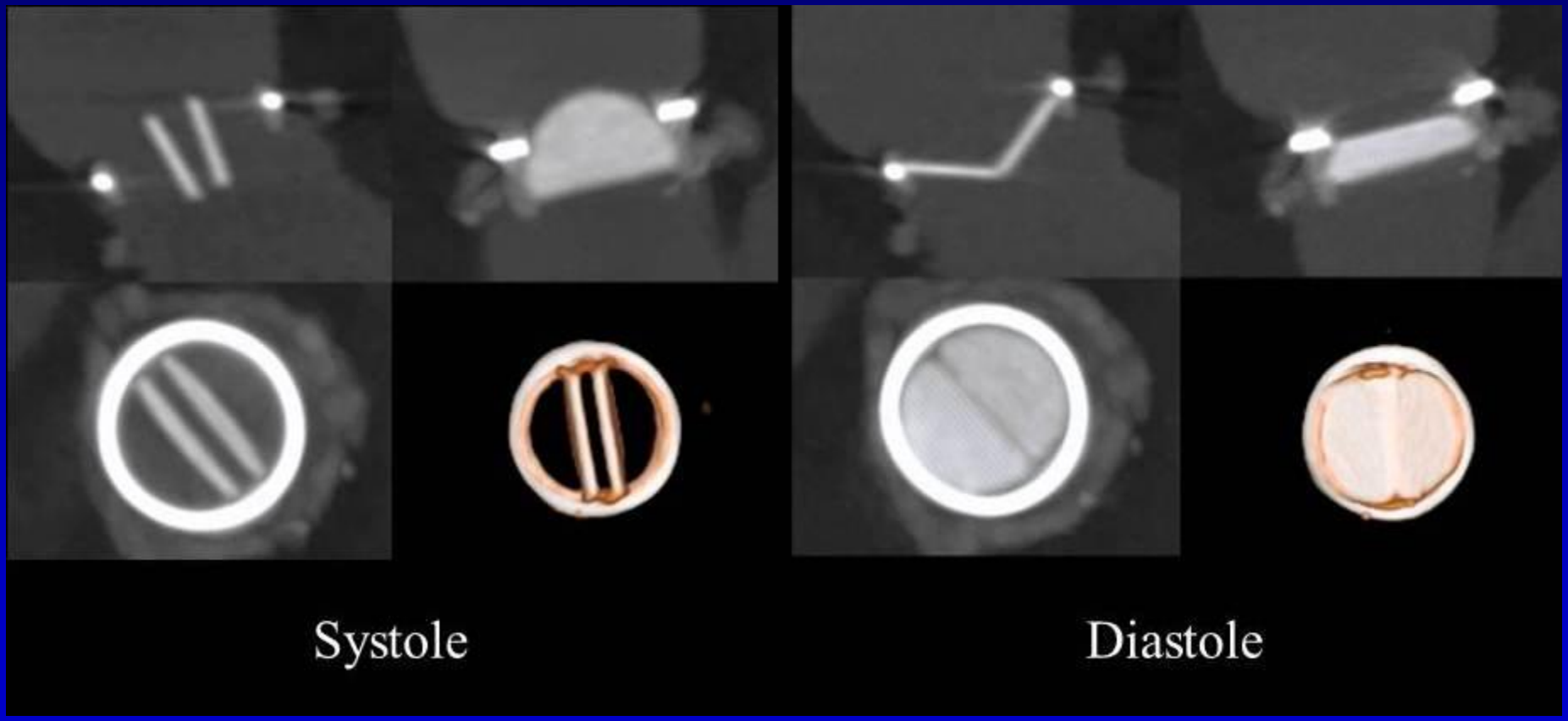
- Bjork-Shiley monostrut[a]
- Sorin Monoleaflet Allcarbon
- Medtronic-Hall
- Omnicarbon
- Ultracor

Caged ball

- Starr-Edwards
- Smeloff-Cutter



[a]Indicates withdrawn from market.


Systole
Diastole

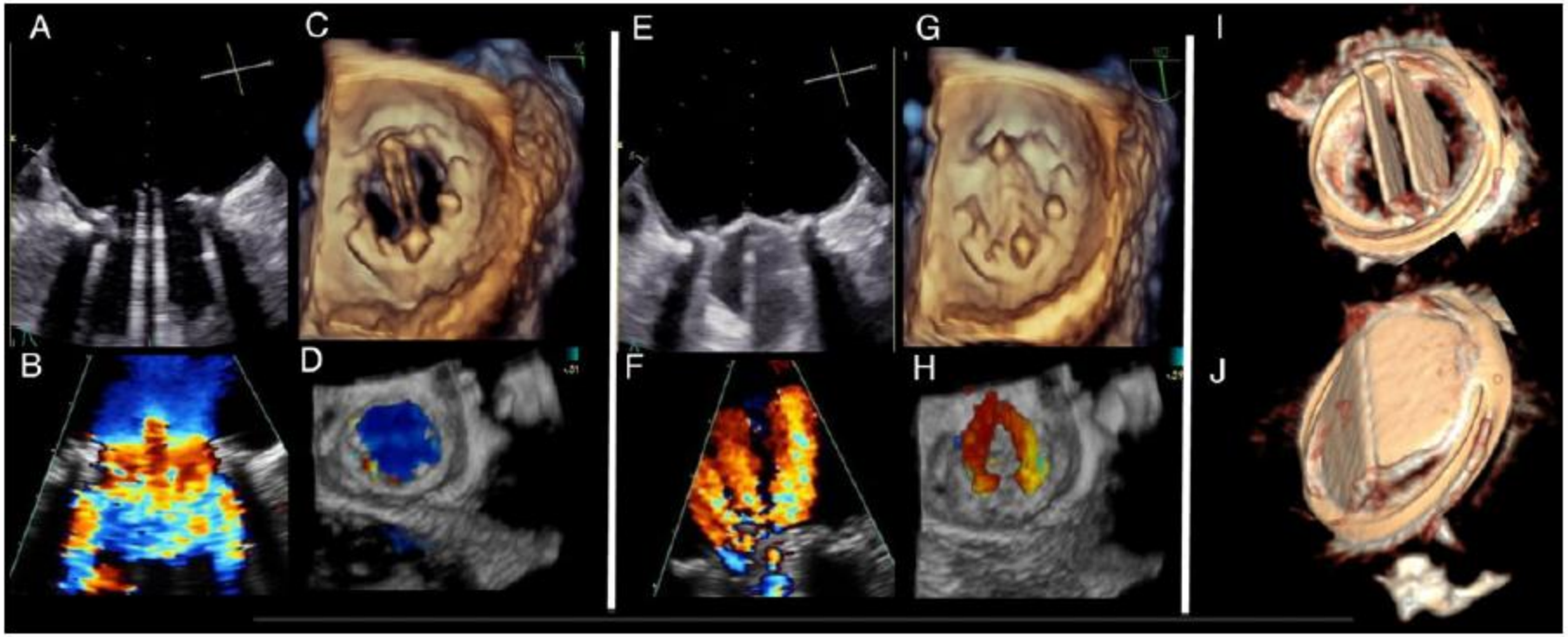
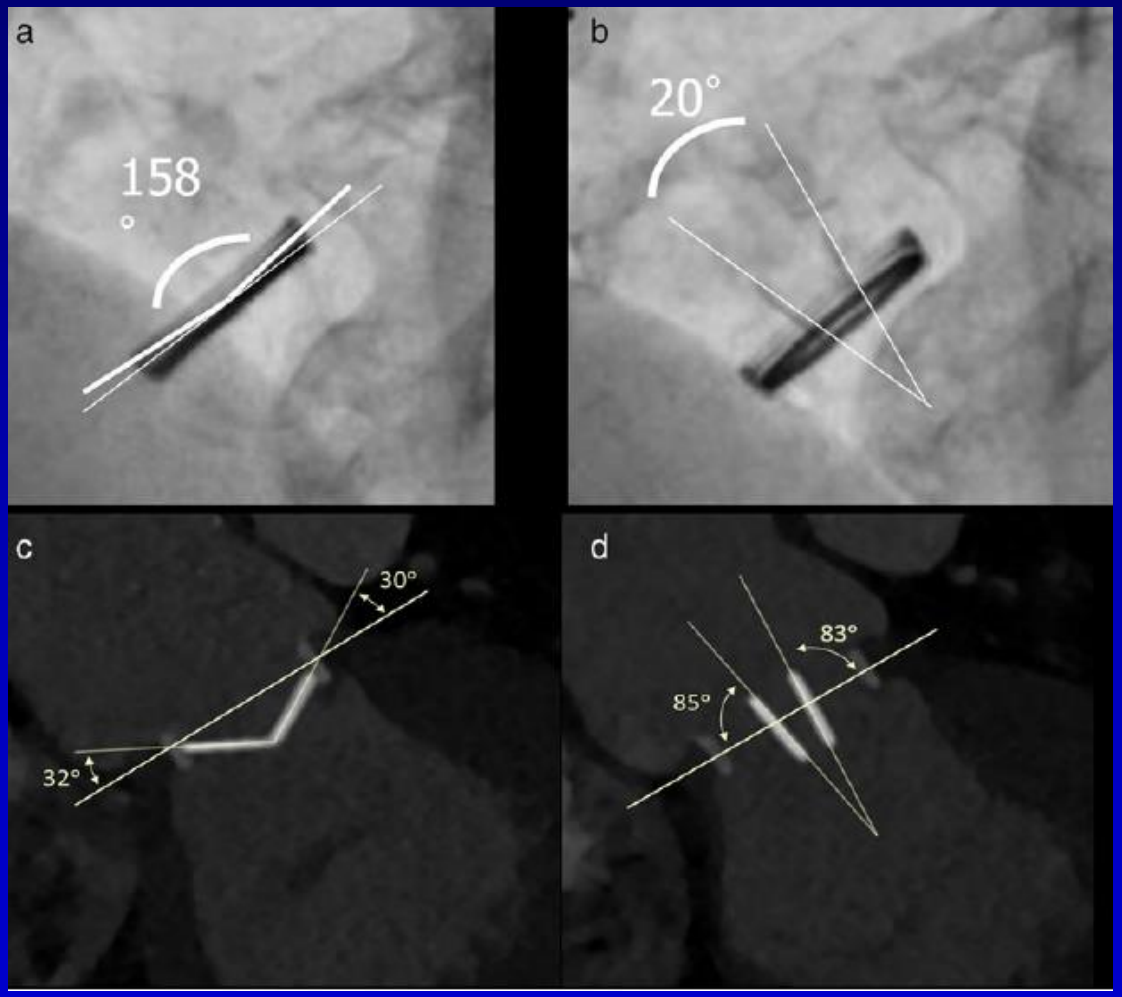


Figure 2 Mechanical valve in mitral position: normal appearance. 2D and 3D transoesophageal echocardiographic (TOE) appearance of a normally functioning mechanical valve in mitral position. (*A–D*) 2D and 3D as well as 2D and 3D colour flow appearance of a bileaflet mechanical valve in the opened position from the atrial perspective. Note the two lateral semi-circular orifices and the central slit-like orifice both visible in 2D and 3D TOE. Note the normal anterograde colour flow Doppler and the flow acceleration at the level of the three orifices in 2D TOE (*B*). (*E–H*) 2D and 3D as well as 2D and 3D colour flow appearance of a bileaflet mechanical valve in the closed position from the atrial perspective. Note the normal appearance of the retrograde colour flow Doppler showing physiologic 'washing jets' for this type of prosthesis in 2D (*F*) and 3D colour flow imaging (*H*). The volumetric reconstructed cardiac computed tomography scan of the bileaflet valve from the atrial (open, *I*) and ventricular (close, *J*) perspective.

Cinefluorscopy and cardiac CT of mechanical bileaflet valve



Cinefluoroscopy of mechanical tilting disk valve

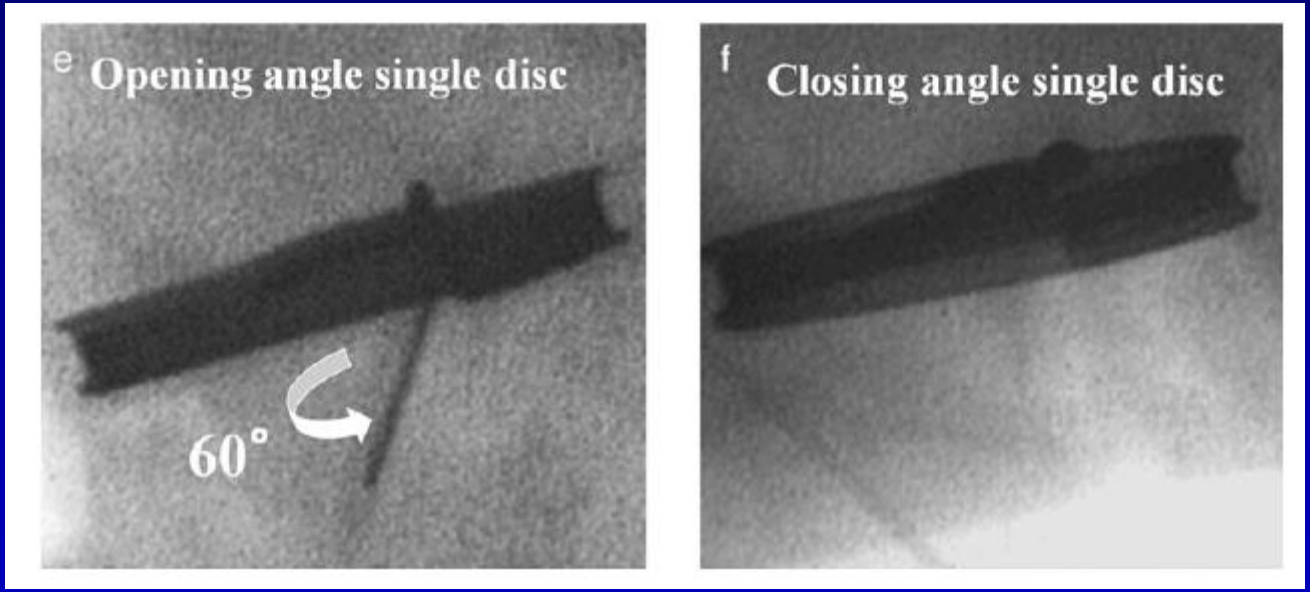


Table 6 Mechanical valves: opacification and opening angles

	Prosthesis materials		Open (Degrees)	Closed (Degrees)
	Housing	Occluder		
Caged-ball valves				
Starr-Edwards	Three (aortic) or four-strut (mitral) cobalt-chrome alloy cage	Silicone rubber	N/A	N/A
Tilting disc valves				
Björk–Shiley	Cobalt-chrome alloy	Silicon alloyed pyrolytic carbon on graphite substrate with radio-opaque tantalum marker	60 (<1981) 70 (>1981)	0
Medtronic-Hall	Titanium alloy	Silicon alloyed pyrolytic carbon on tungsten-loaded graphite substrate	75 (aortic) 70 (mitral)	0
Omniscience	Titanium alloy	Silicon alloyed pyrolytic carbon on tungsten-loaded graphite substrate	80	12
Omnicarbon	Pyrolytic carbon over graphite substrate	Silicon alloyed pyrolytic carbon on tungsten-loaded graphite substrate	80	12
Sorin Allcarbon	Cobalt-chromium alloy coated with a thin layer of pyrolytic carbon	Silicon alloyed pyrolytic carbon on tungsten-loaded graphite substrate	60	0
Bileaflet valves				
ATS Medical	Pyrolytic carbon over graphite substrate with metallic band	Silicon alloyed pyrolytic carbon on tungsten-loaded graphite substrate	85	25
Carbomedics	Solid pyrolytic carbon with titanium stiffening ring metallic band	Silicon alloyed pyrolytic carbon on tungsten-loaded graphite substrate	78–80	15
Edwards Tekna (previously Duromedics)	Solid pyrolytic carbon with titanium stiffening ring	Silicon alloyed pyrolytic carbon on tungsten-loaded graphite substrate	73–77	15
St Jude Medical	Pyrolytic carbon over graphite substrate with metallic band	Silicon alloyed pyrolytic carbon on tungsten-loaded graphite substrate	85	30 (19–25 mm) 25 (27–31 mm)
On-X	Pyrolytic carbon with graphite substrate with titanium alloy bands	Pure pyrolytic carbon on tungsten-loaded graphite substrate	85–90	40
Bicarbon	Cobalt-chromium alloy coated with a thin layer of pyrolytic carbon	Silicon alloyed pyrolytic carbon on tungsten-loaded graphite substrate	80	20

Leaflet angles relative to the plane of the orifice ring as provided by the manufacturers. Note that the angles are measured using the same approach by cardiac computed tomography. Conversely, on cinefluoroscopy, opening and closing angle in bileaflet PHVs are defined as the angle between discs in the fully open and closed positions, respectively. This means that the opening angle is the angle between the two discs (generally $<30^{\circ}$ and in the majority of valves $<20^{\circ}$). The closing angle is usually $>120^{\circ}$–130°.

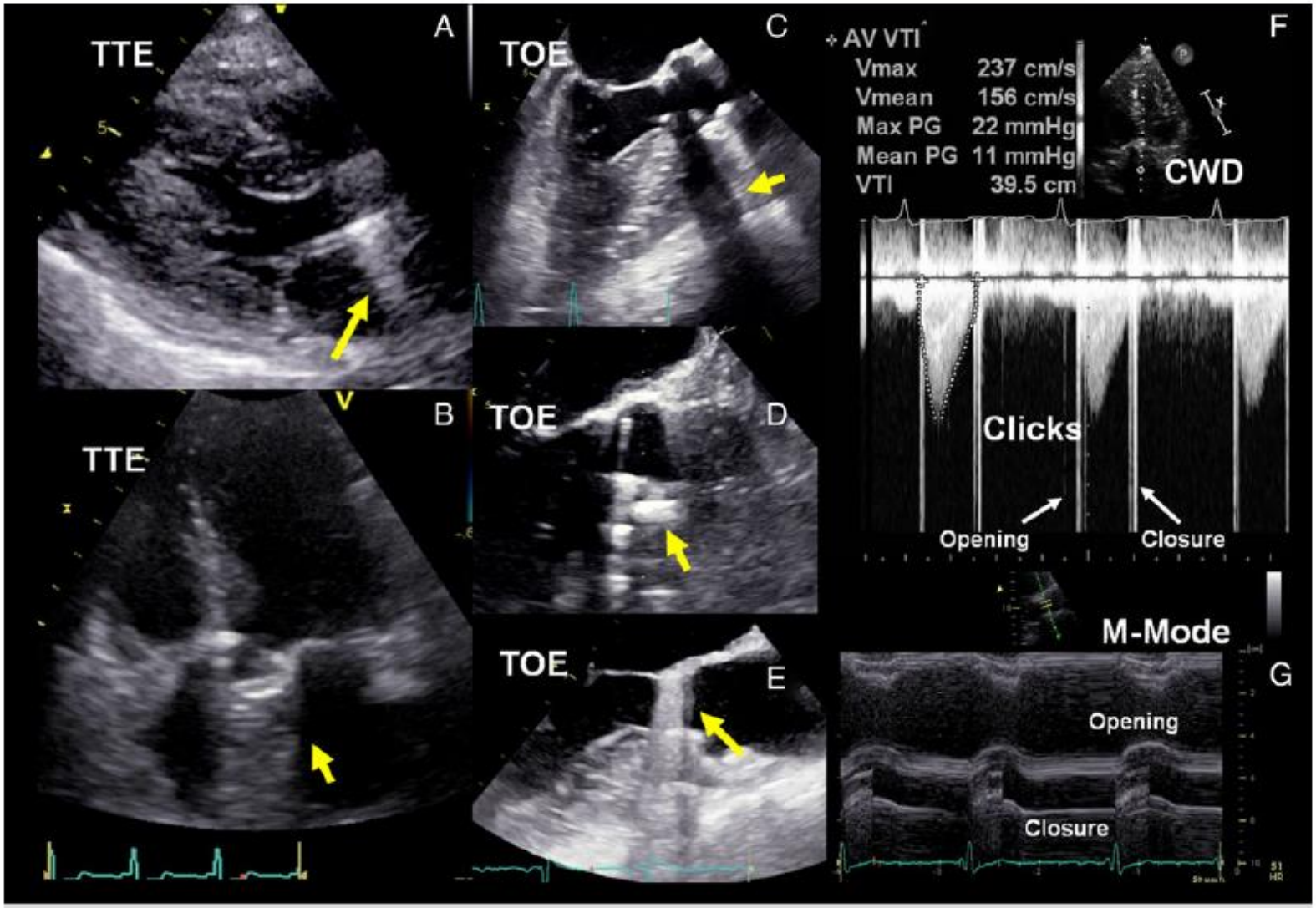


Figure 4 Mechanical valve in aortic position: normal appearance. Acoustic shadowing and reverberations seen with 2D transthoracic and transoesophageal echocardiography when imaging a mechanical valve in aortic position depending on the acoustic view used (*A*–*E*, yellow arrows). (*F*) Continuous wave Doppler (CWD) signal showing the opening and closing clicks (white arrows) of a normally functioning aortic valve, an early peak velocity and a normal mean and peak pressure gradient across the prosthesis. (*G*) M-mode showing normal opening and closure of the discs.

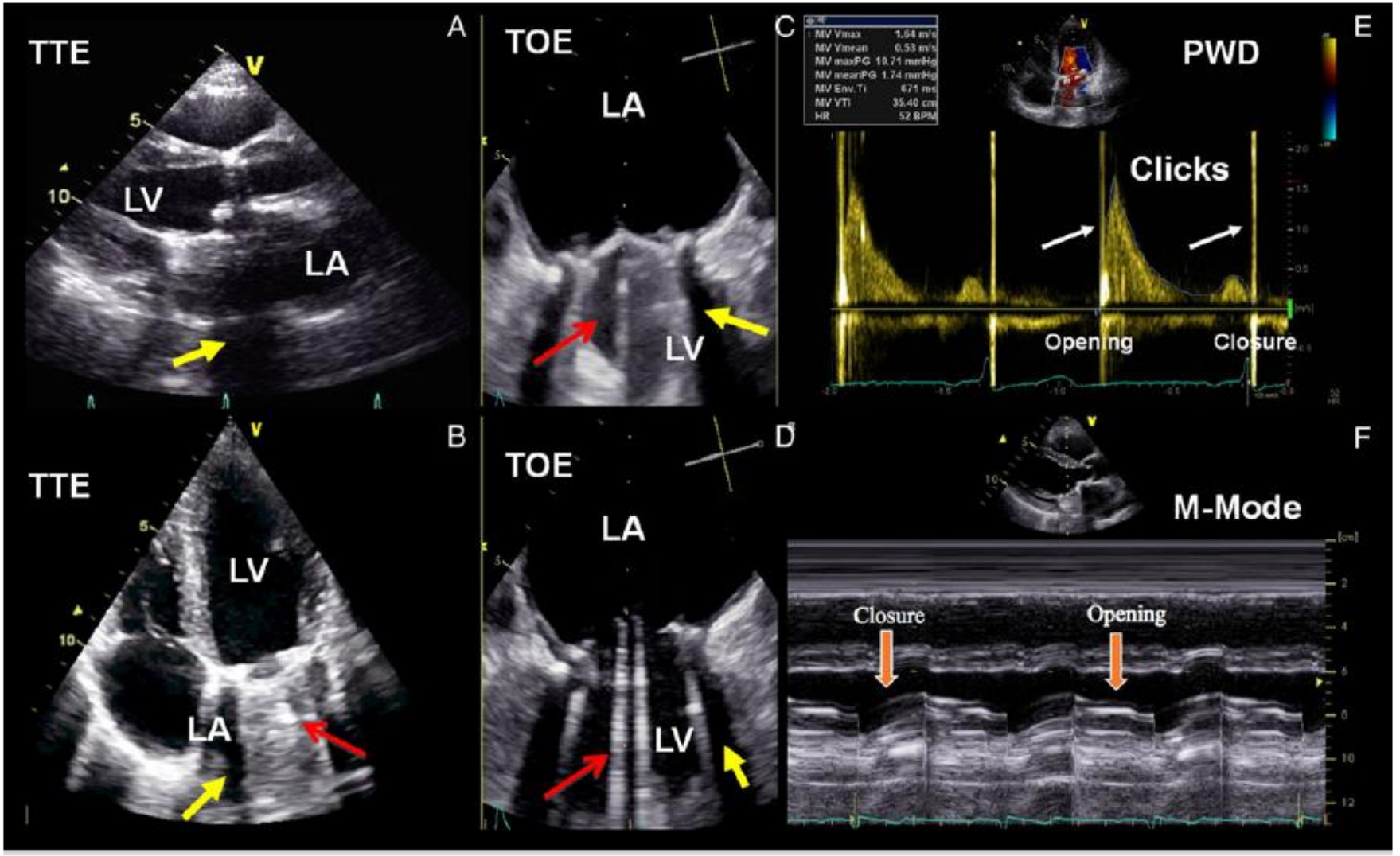
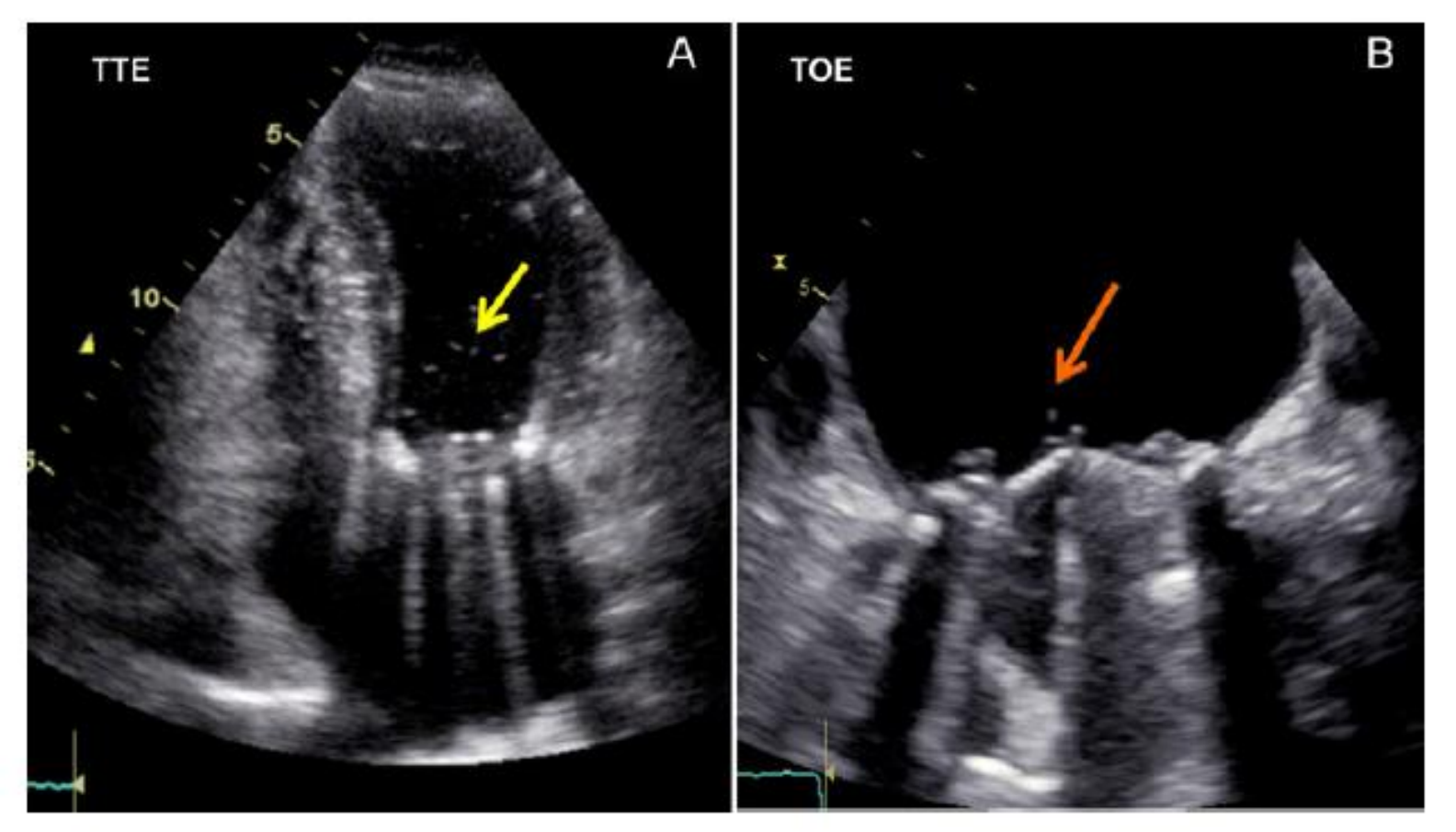


Figure 5 Mechanical valve in mitral position: normal appearance. Acoustic shadowing and reverberations seen with 2D transthoracic and transoesophageal echocardiography when imaging a mechanical valve in mitral position depending on the acoustic view used (*A* and *B*, acoustic shadowing and reverberations on the atrial side (LA) vs. *C* and *D* on the ventricular (LV) side. (*F*) Pulsed wave Doppler (PWD) signal showing the opening and closing clicks (white arrows) of a normally functioning mitral valve. M-mode showing normal opening and closure of the discs.

Mechanical value in mitral position : cavitation and strands



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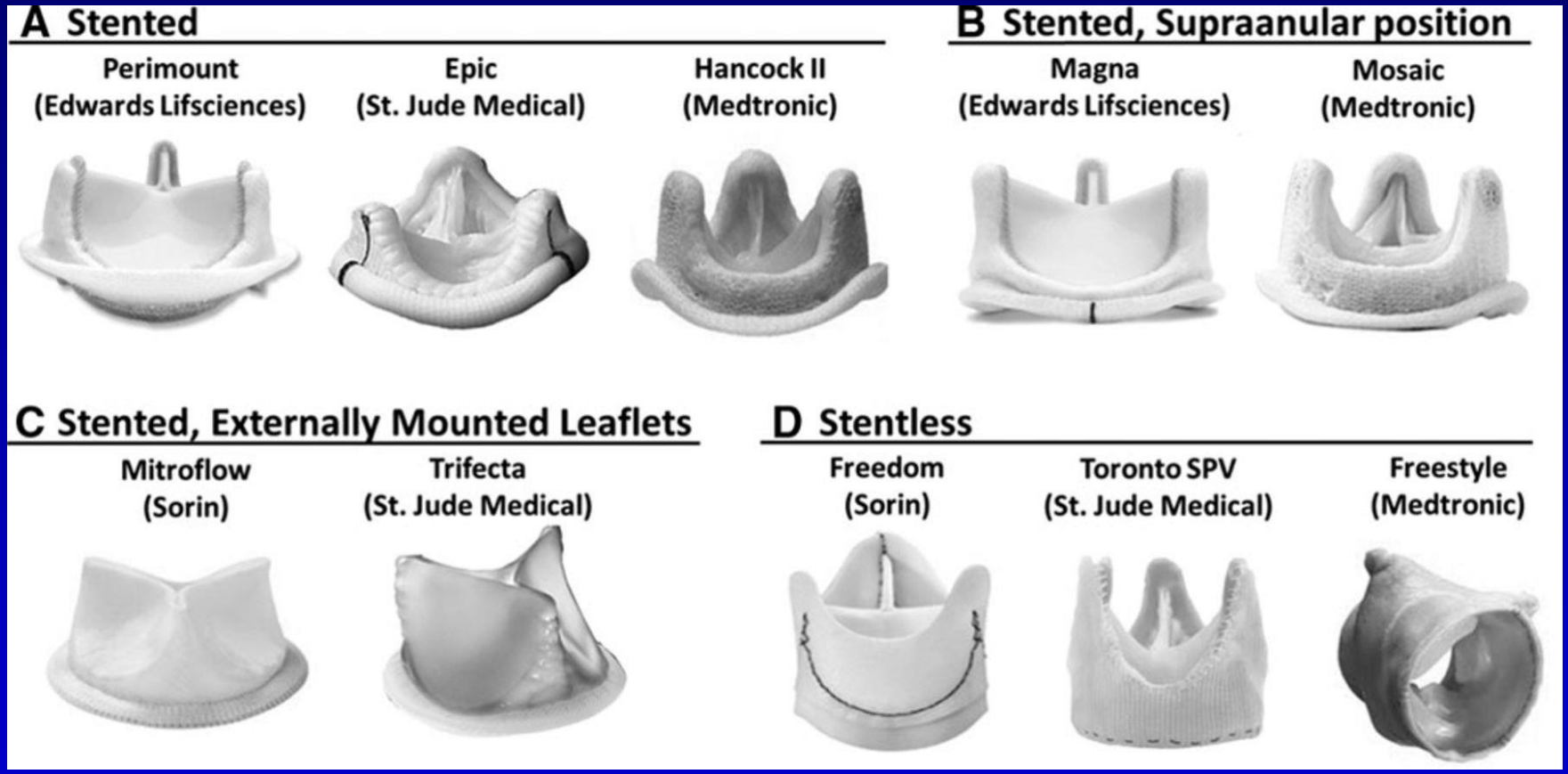
Biological prosthetic heart valves



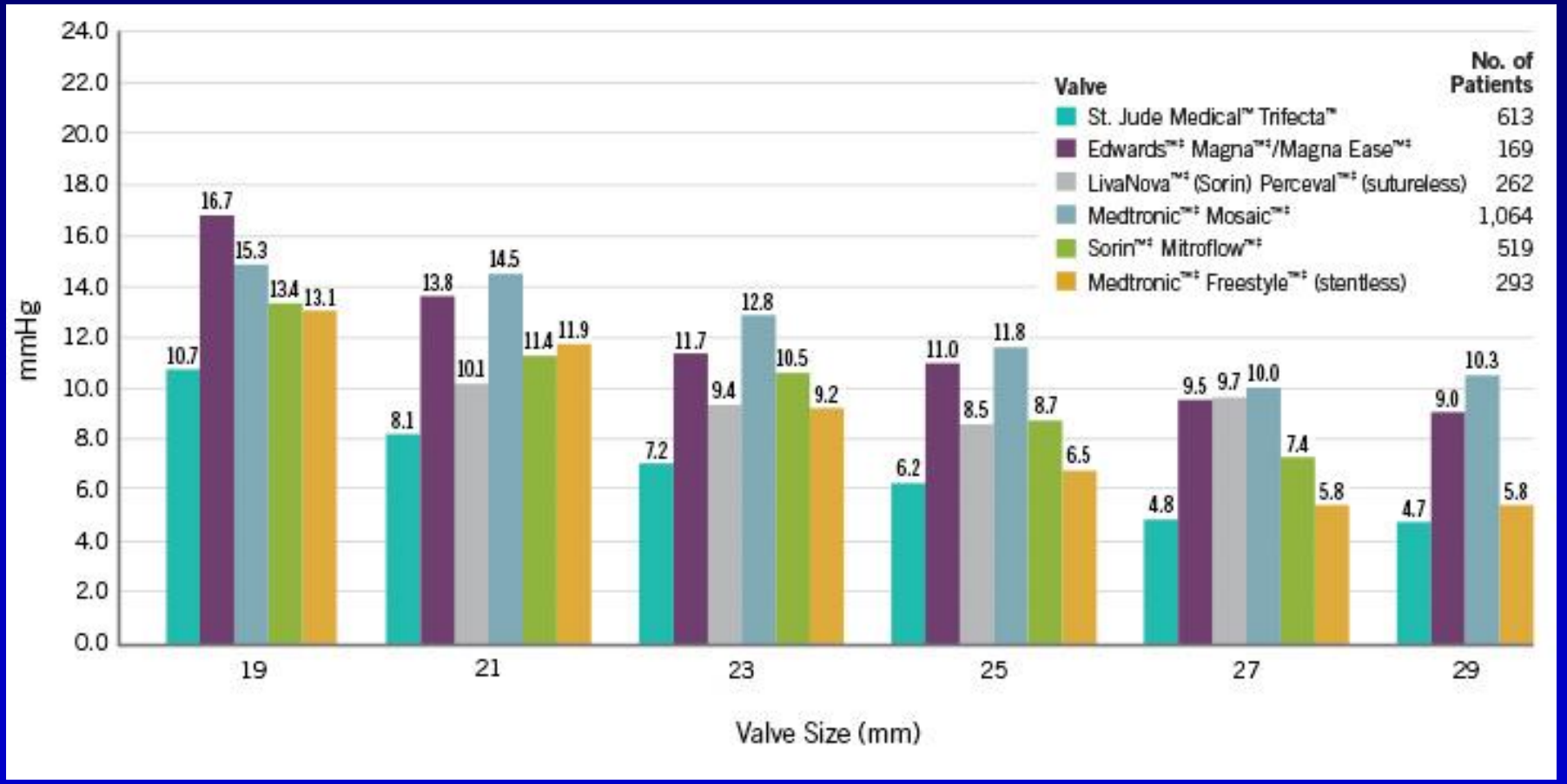
What do you measure routinely in prostethic valves ?

- Early after surgery ?
- During later follow-up ?

Mean gradients of mechanical valves

Table-3: Mean gradients of St. Jude Prosthesis.		
Valve	**Size (mm)**	**Gradient (mm Hg) Mean ± S.D.**
Mitral	21	4.50 ± 0.71
	25	4.5 ± 0.83
	27	3.81 ± 0.75
	29	3.65 ± 0.69
	31	3.50 ± 0.76
	Overall Mean gradient	3.83 ± 0.81
Aortic	19	12.79 ± 0.89
	21	11.88 ± 0.98
	23	11.36 ± 1.28
	25	11.06 ± 1.2
	27	11 ± 1.41
	29	9.67 ± 1.53
	Overall Mean gradient	11.72 ± 1.24

Mean gradients of bioprosthetic valves

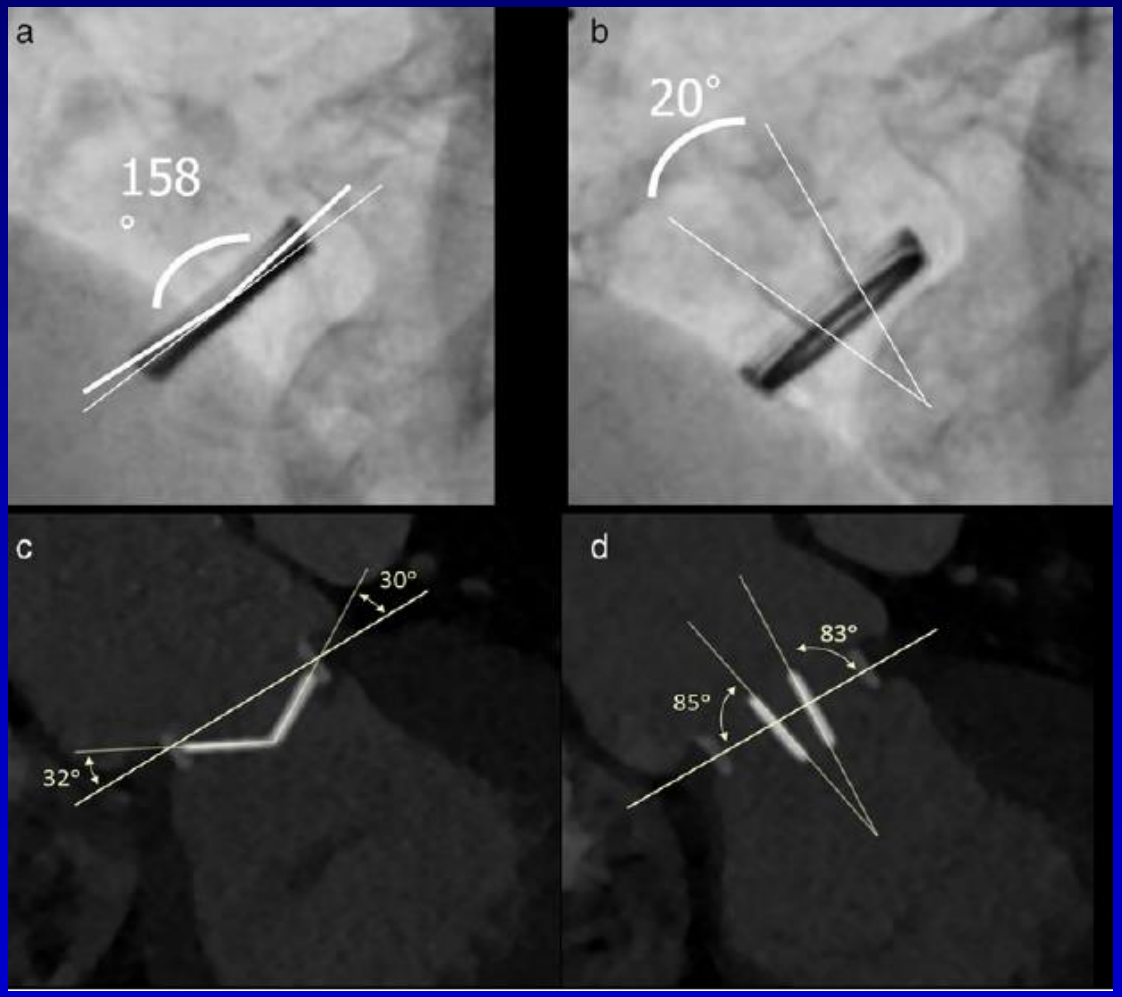


Measurements beyond gradients

The effective orifice area (EOA)

The Doppler velocity index (DVI)

Cinefluorscopy and cardiac CT of mechanical bileaflet valve



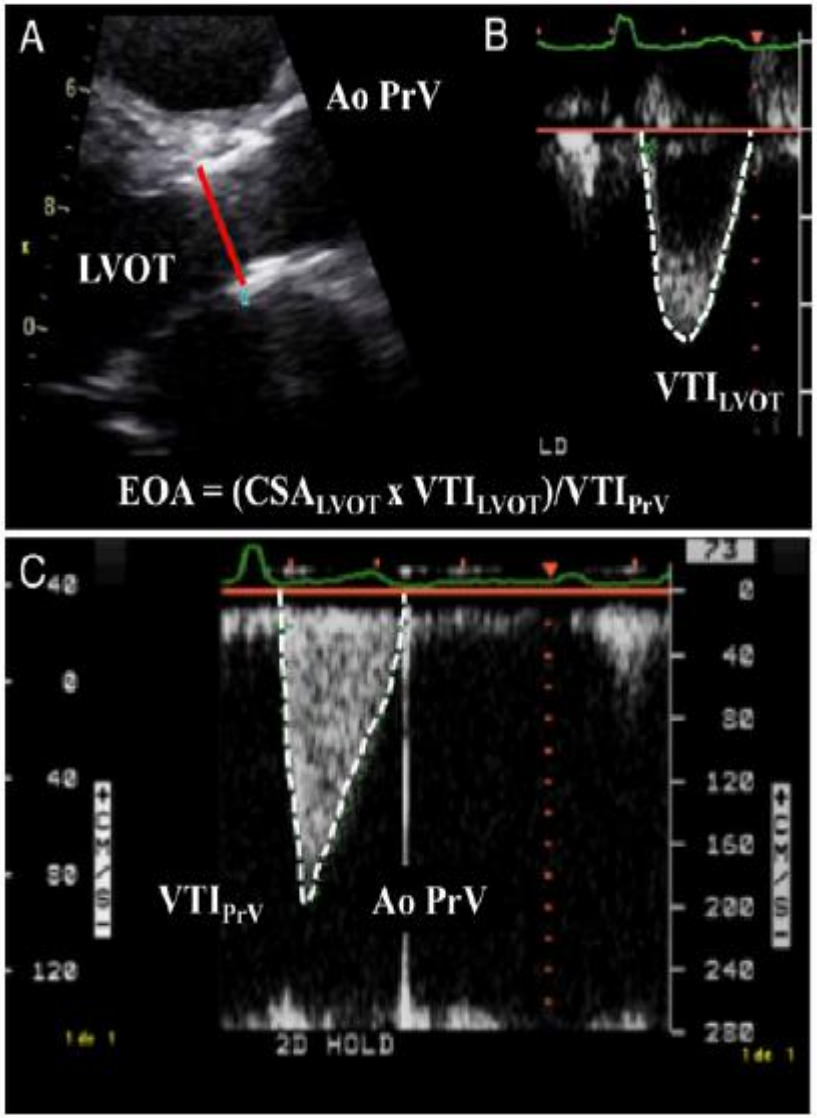


Figure 7 Aortic prosthesis EOA calculation using the continuity equation. The LVOT diameter is measured in mid-systole from the parasternal long-axis view in a zoomed mode, from inner-edge to inner-edge (*A*). The cross-sectional area (CSA) of the LVOT is calculated from the LVOT diameter assuming that the LVOT is circular ($CSA = \Pi \times LVOTd^2/4$). The stroke volume across the prosthesis is computed from multiplying the CSA of the LVOT with the velocity-time integral (VTI) of the LVOT (*B*). The EOA of the prosthesis is then calculated by dividing the stroke volume by the VTI_{PrV} of the transprosthetic flow obtained with continuous wave Doppler (*C*).

Particular attention should be paid not to mistake the inner border of the prosthesis stent/ring for the inner edge of the LVOT. Any error in the measurement of LVOT diameter will be squared in the calculation of the EOA. For an LVOT diameter of 2.0 cm, a 10% error in measurement (1.8 cm) results in a 19% error in calculated EOA. It is important to emphasize that the substitution of the LVOT diameter by the labelled prosthesis size in the continuity equation is not a valid method to determine the EOA of aortic prostheses.[109]

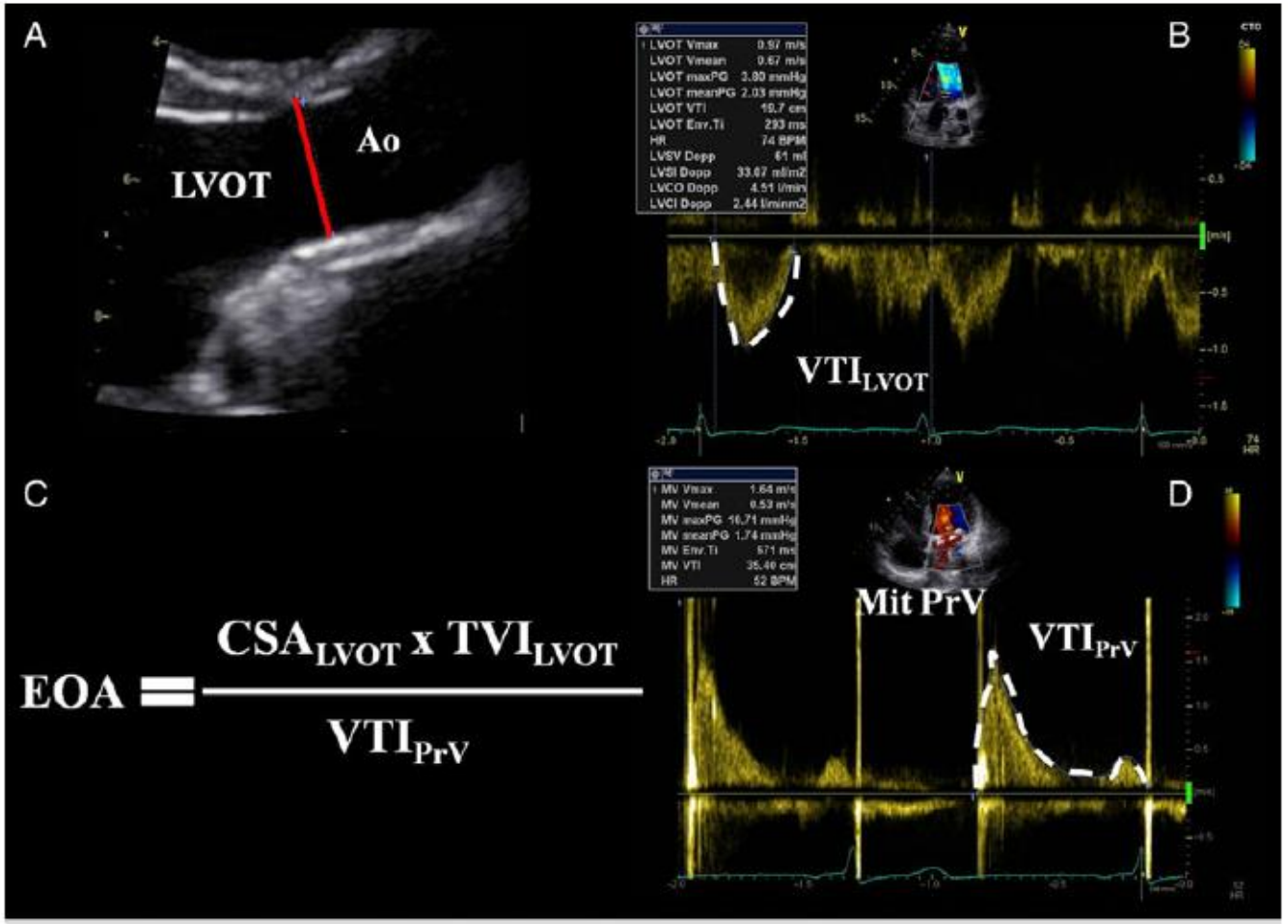


Figure 8 Mitral prosthesis EOA calculation using the continuity equation. The stroke volume across the aortic valve is calculated as described in *Figure 7*, *Panels* (*A*) and (*B*). The EOA of the mitral prosthesis is calculated by dividing the left ventricle stroke volume by the VTI_{PrV} of the trans-prosthetic flow obtained with continuous wave Doppler (*C* and *D*).

Table 7 Normal reference values of effective orifice areas for the prosthetic aortic valves

Prosthetic valve size (mm)	19	21	23	25	27	29
Stented bioprosthetic valves						
Mosaic	1.1 ± 0.2	1.2 ± 0.3	1.4 ± 0.3	1.7 ± 0.4	1.8 ± 0.4	2.0 ± 0.4
Hancock II	–	1.2 ± 0.2	1.3 ± 0.2	1.5 ± 0.2	1.6 ± 0.2	1.6 ± 0.2
Carpentier-Edwards Perimount	1.1 ± 0.3	1.3 ± 0.4	1.5 ± 0.4	1.8 ± 0.4	2.1 ± 0.4	2.2 ± 0.4
Carpentier-Edwards Magna	1.3 ± 0.3	1.5 ± 0.3	1.8 ± 0.4	2.1 ± 0.5	–	–
Biocor (Epic)	1.0 ± 0.3	1.3 ± 0.5	1.4 ± 0.5	1.9 ± 0.7	–	–
Mitroflow	1.1 ± 0.2	1.2 ± 0.3	1.4 ± 0.3	1.6 ± 0.3	1.8 ± 0.3	–
Trifecta	1.4	1.6	1.8	2.0	2.2	2.4
Stentless bioprosthetic valves						
Medtronic Freestyle	1.2 ± 0.2	1.4 ± 0.2	1.5 ± 0.3	2.0 ± 0.4	2.3 ± 0.5	–
St Jude Medical Toronto SPV	–	1.3 ± 0.3	1.5 ± 0.5	1.7 ± 0.8	2.1 ± 0.7	2.7 ± 1.0
Prima Edwards	–	1.3 ± 0.3	1.6 ± 0.3	1.9 ± 0.4	–	–
Mechanical valves						
Medtronic-Hall	1.2 ± 0.2	1.3 ± 0.2	–	–	–	–
St Jude Medical Standard	1.0 ± 0.2	1.4 ± 0.2	1.5 ± 0.5	2.1 ± 0.4	2.7 ± 0.6	3.2 ± 0.3
St Jude Medical Regent	1.6 ± 0.4	2.0 ± 0.7	2.2 ± 0.9	2.5 ± 0.9	3.6 ± 1.3	4.4 ± 0.6
MCRI On-X	1.5 ± 0.2	1.7 ± 0.4	2.0 ± 0.6	2.4 ± 0.8	3.2 ± 0.6	3.2 ± 0.6
Carbomedics Standard and Top Hat	1.0 ± 0.4	1.5 ± 0.3	1.7 ± 0.3	2.0 ± 0.4	2.5 ± 0.4	2.6 ± 0.4
ATS Medical[a]	1.1 ± 0.3	1.6 ± 0.4	1.8 ± 0.5	1.9 ± 0.3	2.3 ± 0.8	–

Effective orifice area is expressed as mean values available in the literature. Further studies are needed to validate these reference values.

[a]For the ATS medical valve, the label valve sizes are 18, 20, 22, 24, and 26 mm. High velocities are common in size 19 or 21 prostheses. Adapted with permission from Ref. 7.

Table 8 Normal reference values of effective orifice areas for the prosthetic mitral valves

Prosthetic valve size (mm)	25	27	29	31	33
Stented bioprosthetic valves					
Medtronic Mosaic	1.5 ± 0.4	1.7 ± 0.5	1.9 ± 0.5	1.9 ± 0.5	–
Hancock II	1.5 ± 0.4	1.8 ± 0.5	1.9 ± 0.5	2.6 ± 0.5	2.6 ± 0.7
Carpentier-Edwards Perimount	1.6 ± 0.4	1.8 ± 0.4	2.1 ± 0.5	–	–
Mechanical valves					
St Jude Medical Standard	1.5 ± 0.3	1.7 ± 0.4	1.8 ± 0.4	2.0 ± 0.5	2.0 ± 0.5
MCRI On-X[a]	2.2 ± 0.9	2.2 ± 0.9	2.2 ± 0.9	2.2 ± 0.9	2.2 ± 0.9

Effective orifice area is expressed as mean values available in the literature. Further studies are needed to validate these reference values.
[a]The On-X valve has just 1 size for 27 to 29 and 31 to 33 mm prostheses. In addition, the strut and leaflets are identical for all sizes (25 to 33 mm); only the size of the sewing cuff is different. Adapted with permission from Ref. 7.

Doppler velocity index

- When reliable measure of the LVOT diameter cannot be obtained to calculate the EOA
- Less dependent on valve size

- Aorta valve : normal DVI > 0,30-0,35

$$DVI = \frac{\text{peak } V_{LVOT}}{\text{peak } V_{PrV}} \quad \text{or} \quad \frac{VTI_{LVOT}}{VTI_{PrV}}$$

- Mitral valve : normal DVI < 2,2

$$DVI = \frac{VTI_{PrV}}{VTI_{LVOT}}$$

Elevated gradients accross aortic prosthetic valves…

What is your differential diagnosis ?

Elevated gradients accross aortic prosthetic valves

- Prosthesis obstruction (thrombosis and/or pannus)
- Patient/prosthesis mismatch
- Pressure recovery (ascending aorta < 30 mm)

- High output state (eg anemia)
- Aortic regurgitation
- Small size valve (19-21 mm bileaflet valves)
- Subvalvular acceleration

Table 13 Grading aortic prosthetic valve obstruction

	Normal	Possible obstruction	Significant obstruction
Qualitative			
Valve structure and motion	Normal	Often abnormal[a]	Abnormal[a]
Transvalvular flow envelope[b]	Triangular, early peaking	Triangular to intermediate	Rounded, symmetrical
Semi-quantitative			
Acceleration time (ms)[b]	<80	80–100	>100
Acceleration time/LV ejection time ratio	<0.32	0.32–0.37	>0.37
Quantitative			
Flow dependent			
Peak velocity (m/s)[c,d]	<3	3–3.9	≥4
Mean gradient (mmHg)[c,d]	<20	20–34	≥35
Increase in mean gradient during stress echo	<10	10–19	≥20
Increase in mean gradient during follow-up	<10	10–19	≥20
Flow independent			
Effective orifice area (cm^2)[c,e]	>1.1	0.8–1.1	<0.8
Measured EOA vs. normal reference value[c]	Reference ± 1SD	<Reference −1SD	<Reference −2SD
Difference (reference EOA − measured EOA) (cm^2)[c]	<0.25	0.25–0.35	>0.35
Doppler velocity index[c,e]	≥0.35	0.25–0.34	<0.25

See *Table 7* to obtain the normal reference values of effective orifice area for the different models and sizes of prostheses.
SD, standard deviation.
[a]Abnormal mechanical valves: occluder that is immobile or with restricted mobility, thrombus, or pannus; abnormal biologic valves: leaflet thickening/calcification, thrombus, or pannus.
[b]These parameters are affected by LV function and heart rate.
[c]The criteria proposed for these parameters are valid for near normal or normal stroke volume (50–90 mL) and flow rate (200–300 mL/s).
[d]These parameters are more affected by low or high flow states including low LV output and concomitant aortic regurgitation.
[e]This parameter is dependent on the size of the LV outflow tract.

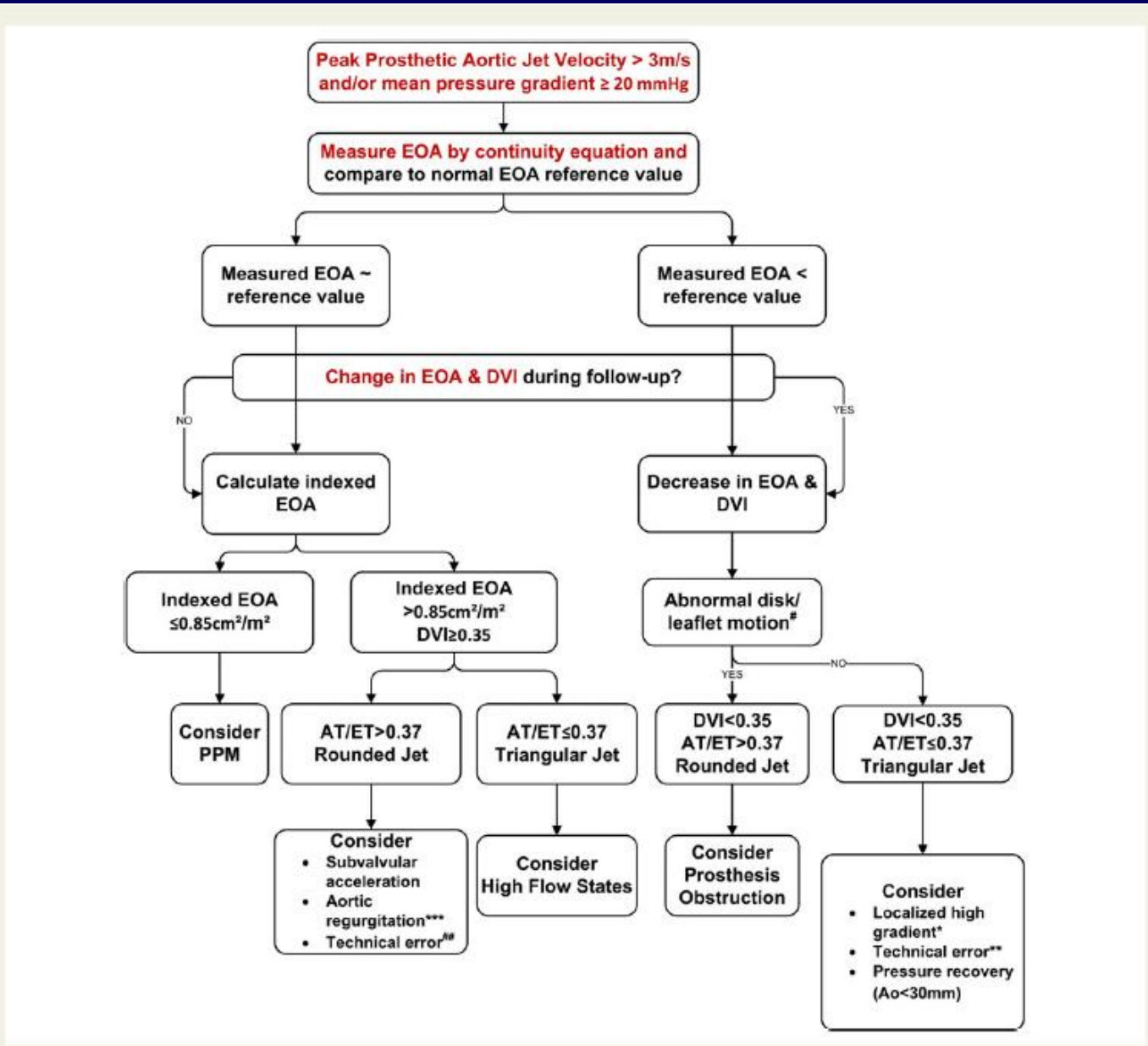


Figure 20 Algorithm for evaluation of high transvalvular aortic gradient. Ao, ascending aorta diameter; AT/ET, acceleration time/ejection time ratio; DVI, Doppler velocity index; EOA, effective orifice area; PPM, patient-prosthesis mismatch. *Bileaflet valves only, small aortic PHV size (19–21 mm). **Consider underestimation of LVOT diameter and/or LVOT VTI. ***Recalculate EOA using RVOT stroke volume. #If leaflet/disc motion unclear by TTE, consider cinefluoroscopy or cardiac CT. ##Consider overestimation of LVOT diameter and/or LVOT VTI.

Interpretation of elevated gradients accross aortic prosthetic valves

Doppler parameter	Expected	Stenosis	PPM	High output	Pressure recovery
Gradient (mmHg)	~ model/size	High	High	High	High
Accel Time (msec)	≤ 100	> 100	≤ 100	≤ 100	≤ 100
AT/ET	≤ 0,37	> 0.37	≤ 0.37	≤ 0.37	≤ 0.37
Abnl leaflet motion	No	Yes	No	No	No
EOA (cm^2)	~ model/size	Low	Expected	Expected	Varies
EOA index (cm^2/m^2)	> 0,85	Low	Low	> 0,85	Varies
DVI	> 0,25	≤ 0,25	> 0,25	> 0,25	Varies
Δ in EOA and DVI	No	Yes	No	No	No