GUIDELINES AND STANDARDS
Echocardiographic Assessment of Valve Stenosis: EAE/ASE Recommendations for Clinical Practice

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Aortic stenosis

Echocardiography has become the standard means for evaluation of aortic stenosis (AS) severity. Cardiac catheterization is no longer recommended except in rare cases when echocardiography is non-diagnostic or discrepant with clinical data.

The primary haemodynamic parameters recommended for clinical evaluation of AS severity are:

- Peak transvalvular velocity
- Mean transvalvular gradient
- Valve area by continuity equation.

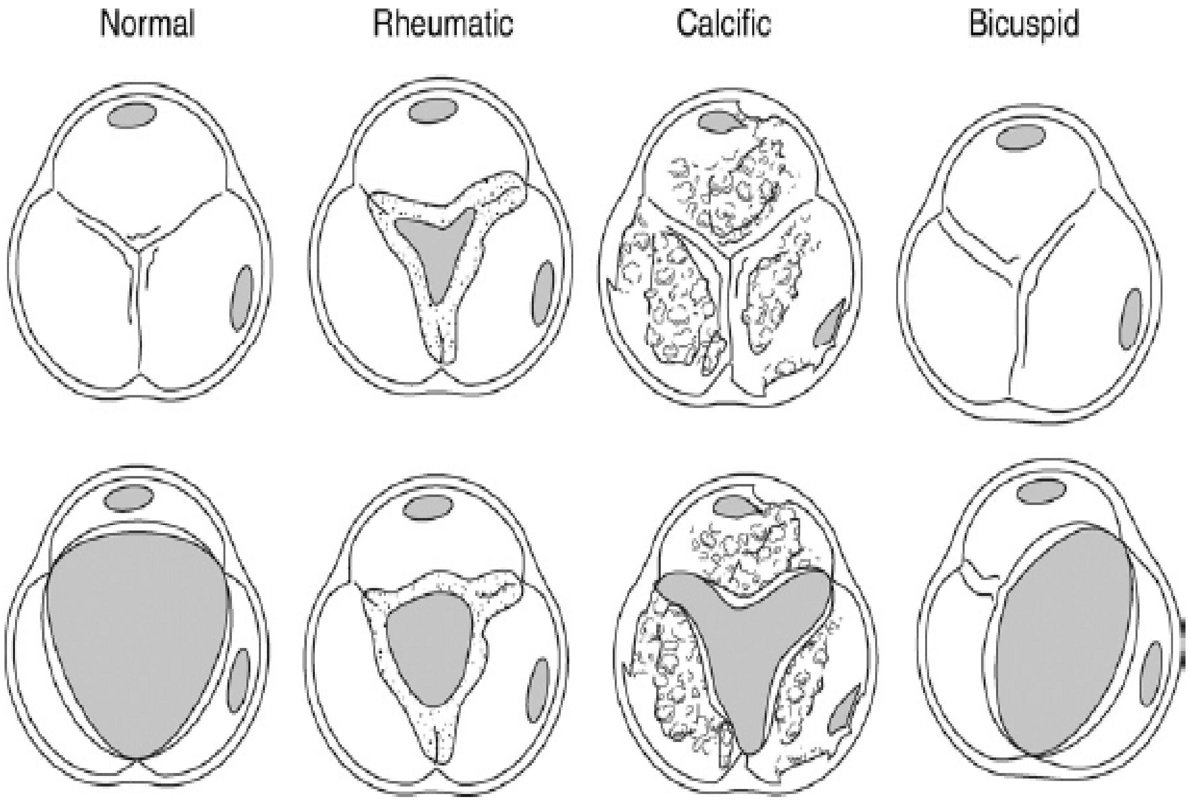

Figure 1 Aortic stenosis aetiology: morphology of calcific AS, bicuspid valve, and rheumatic AS (Adapted from C. Otto, Principles of Echocardiography, 2007).

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Table 1 Recommendations for data recording and measurement for AS quantitation

Data element	Recording	Measurement
LVOT diameter	• 2D parasternal long-axis view • Zoom mode • Adjust gain to optimize the blood tissue interface	• Inner edge to inner edge • Mid-systole • Parallel and adjacent to the aortic valve or at the site of velocity measurement (see text) • Diameter is used to calculate a circular CSA
LVOT velocity	• Pulsed-wave Doppler • Apical long axis or five-chamber view • Sample volume positioned just on LV side of valve and moved carefully into the LVOT if required to obtain laminar flow curve • Velocity baseline and scale adjusted to maximize size of velocity curve • Time axis (sweep speed) 100 mm/s • Low wall filter setting • Smooth velocity curve with a well-defined peak and a narrow velocity range at peak velocity	• Maximum velocity from peak of dense velocity curve • VTI traced from modal velocity
AS jet velocity	• CW Doppler (dedicated transducer) • Multiple acoustic windows (e.g. apical, suprasternal, right parasternal, etc) • Decrease gains, increase wall filter, adjust baseline, and scale to optimize signal • Gray scale spectral display with expanded time scale • Velocity range and baseline adjusted so velocity signal fits but fills the vertical scale	• Maximum velocity at peak of dense velocity curve • Avoid noise and fine linear signals • VTI traced from outer edge of dense signal curve • Mean gradient calculated from traced velocity curve • Report window where maximum velocity obtained
Valve anatomy	• Parasternal long- and short-axis views • Zoom mode	• Identify number of cusps in systole, raphe if present • Assess cusp mobility and commisural fusion • Assess valve calcification

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Table 2 Measures of AS severity obtained by Doppler echocardiography (Part 1)

	Units	Formula / Method	Cutoff for Severe	Concept	Advantages	Limitations
AS jet velocity [8-10,12]	m/s	Direct measurement	4.0	Velocity increases as stenosis severity increase.	Direct measurement of velocity. Strongest predictor of clinical outcome.	Correct measurement requires parallel alignment of ultrasound beam. Flow dependent.
Mean gradient [8-10]	mm Hg	$\Delta P = \sum 4v^2 / N$	40 or 50	Pressure gradient calculated from velocity using the Bernoulli equation	Mean gradient is averaged from the velocity curve. Units comparable to invasive measurements.	Accurate pressure gradients depend on accurate velocity data. Flow dependent
Continuity equation valve area [16,17,23]	cm^2	$AVA = (CSA_{LVOT} \times VTI_{LVOT}) / VTI_{AV}$	1.0	Volume flow proximal to and in the stenotic orifice is equal.	Measures effective orifice area. Feasible in nearly all patients. Relatively flow independent.	Requires LVOT diameter and flow velocity data, along with aortic velocity. Measurement error more likely.
Simplified continuity equation [16,23]	cm^2	$AVA = (CSA_{LVOT} \times V_{LVOT}) / V_{AV}$	1.0	The ratio of LVOT to aortic velocity is similar to the ratio of VTIs with native aortic valve stenosis.	Uses more easily measured velocities instead of VTIs.	Less accurate if shape of velocity curves is atypical.
Velocity Ratio [15,18]	none	$VR = \frac{V_{LVOT}}{V_{AV}}$	0.25	Effective aortic valve area expressed as a proportion of the LVOT area.	Doppler-only method. No need to measure LVOT size, less variability than continuity equation.	Limited longitudinal data. Ignores LVOT size variability beyond patient size dependence
Planimetry of Anatomic Valve Area [26, 34]	cm^2	TTE, TEE, 3D-echo	1.0	Anatomic (geometric) cross-sectional area of the aortic valve orifice as measured by 2D or 3D echo.	Useful if Doppler measurements are unavailable.	Contraction coefficient (anatomic / effective valve area) may be variable. Difficult with severe valve calcification.
LV % Stroke Work Loss [27]	%	$\%SWL = \frac{\overline{\Delta P}}{\overline{\Delta P} + SBP} \cdot 100$	25	Work of the LV wasted each systole for flow to cross the aortic valve, expressed as a % of total systolic work	Very easy to measure. Related to outcome in one longitudinal study.	Flow-dependent. Limited longitudinal data
Recovered Pressure Gradient [13, 32]	mm Hg	$P_{distal} - P_{vc} = 4 \cdot v^2 \cdot 2 \cdot \frac{AVA}{AA}\left(1 - \frac{AVA}{AA}\right)$	-	Pressure difference between the LV and the aorta, slightly distal to the *vena contracta*, where distal pressure has increased.	Closer to the global hemodynamic burden caused by AS in terms of adaptation of the cardiovascular system. Relevant at high flow states and in patients with small ascending aorta.	Introduces complexity and variability related to the measurement of the ascending aorta. No prospective studies showing real advantages over established methods.

Table 2 Measures of AS severity obtained by Doppler echocardiography (Part 2)

	Units	Formula / Method	Cutoff for Severe	Concept	Advantages	Limitations
Energy Loss Index [35]	cm^2/m^2	$ELI = \frac{AVA \cdot AA}{AA - AVA} \Big/ BSA$	0.5	Equivalent to the concept of AVA, but correcting for distal recovered pressure in the ascending aorta	(As above) Most exact measurement of AS in terms of flow-dynamics. Increased prognostic value in one longitudinal study.	Introduces complexity and variability related to the measurement of the ascending aorta.
Valvulo-Arterial Impedance[31]	mm Hg/ml/m^2	$Z_{VA} = \frac{\overline{\Delta P_{net}} + SBP}{SVI}$	5	Global systolic load imposed to the LV, where the numerator represents an accurate estimation of total LV pressure	Integrates information on arterial bead to the hemodynamic burden of AS, and systemic hypertension is a frequent finding in calcific-degenerative disease.	Although named "impedance", only the steady-flow component (i.e. mean resistance) is considered. No longitudina prospective study available.
Aortic Valve Resistance [28, 29]	dynes/s/cm^5	$AVR = \frac{\overline{\Delta P}}{\overline{Q}} = \frac{\overline{4 \cdot v^2}}{\cdot r_{LVOT}^2 \cdot v_{LVOT}} \cdot 1333$	280	Resistance to flow caused by AS, assuming the hydrodynamics of a tubular (non flat) stenosis.	Initially suggested to be less flow-dependent in low-flow AS, but subsequently shown to not be true.	Flow dependence. Limited prognostic value. Unrealistic mathematic modelling of flow-dynamics of AS.
Projected Valve Area at Normal Flow Rate [30]	cm^2	$AVA_{proj} = AVA_{rest} + VC \cdot (250 - Q_{rest})$	1.0	Estimation of AVA at normal flow rate by ploting AVA vs. flow and calculating the slope of regression (DSE)	Accounts for the variable changes in flow during DSE in low flow low gradient AS, provides improved interpretation of AVA changes	Clinical impact still to be shown. Outcome of low-flow AS appears closer related to the presence / absence of LV contractility reserve.

Recommendation for clinical application: (1) appropriate in all patients with AS (yellow); (2) reasonable when additional information is needed in selected patients (green); and (3) not recommended for clinical use (blue).

VR, Velocity ratio; TVI, time-velocity integral; LVOT, LV outflow tract; AS jet; TTE and TEE, transthoracic and transesophageal echocardiography; SWL, stroke work loss; *P*, mean transvalvular systolic pressure gradient; SBP, systolic blood pressure; *P*distal, pressure at the ascending aorta; *P*vc, pressure at the *vena contracta*; AVA, continuity-equation-derived aortic valve area; *v*, velocity of AS jet; AA, size of the ascending aorta; ELI, energy-loss coefficient; BSA, body-surface area; AVR, aortic valve resistance; *Q* , mean systolic transvalvular flow-rate; AVAproj, projected aortic valve area; AVArest, AVA at rest; VC, valve compliance derived as the slope of regression line fitted to the AVA versus Q plot; *Q*rest, flow at rest; DSE, dobutamine stress echocardiography; N, number of instantaneous measurements.

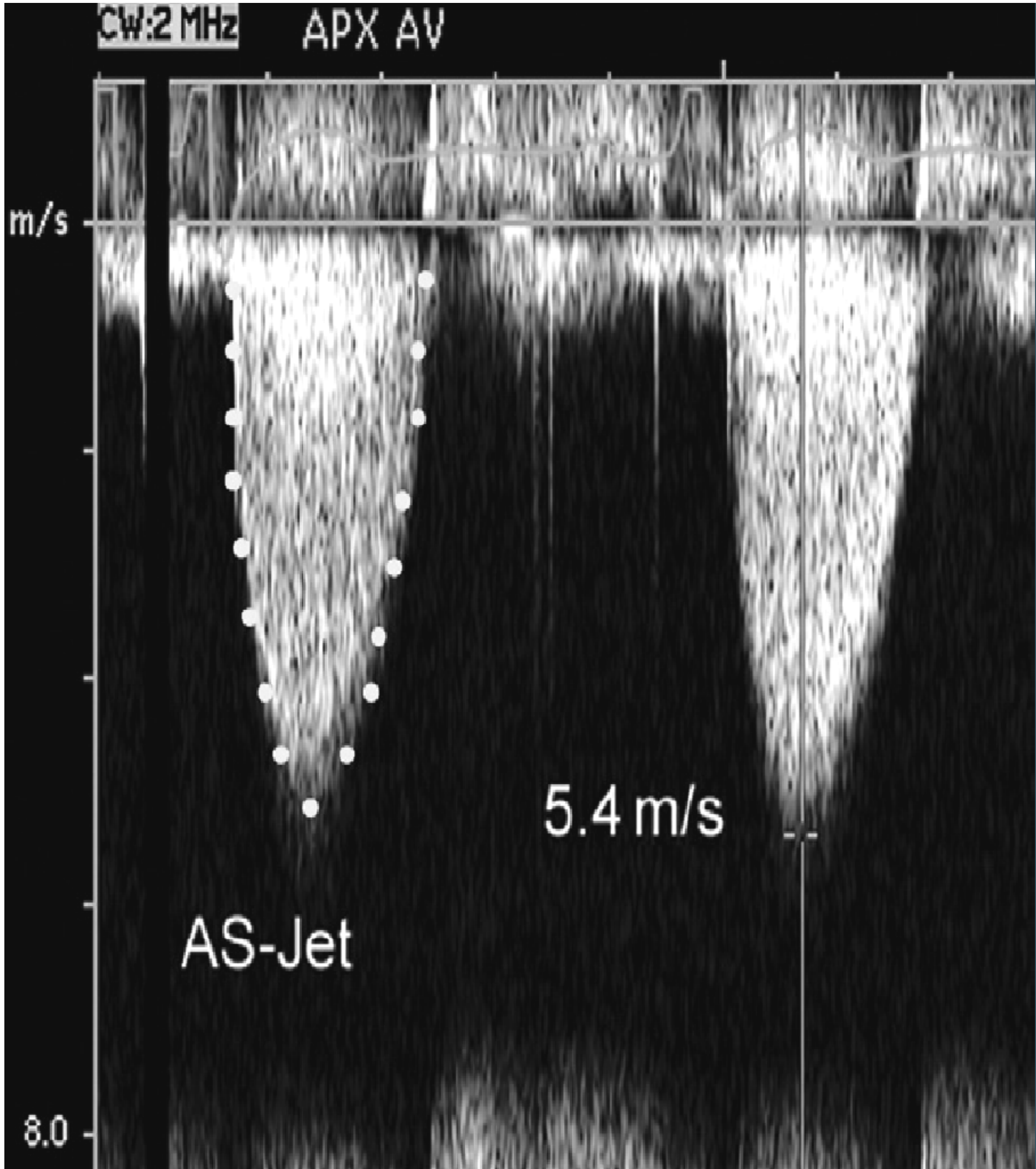

Figure 2 Continuous-wave Doppler of severe aortic stenosis jet showing measurement of maximum velocity and tracing of the velocity curve to calculate mean pressure gradient

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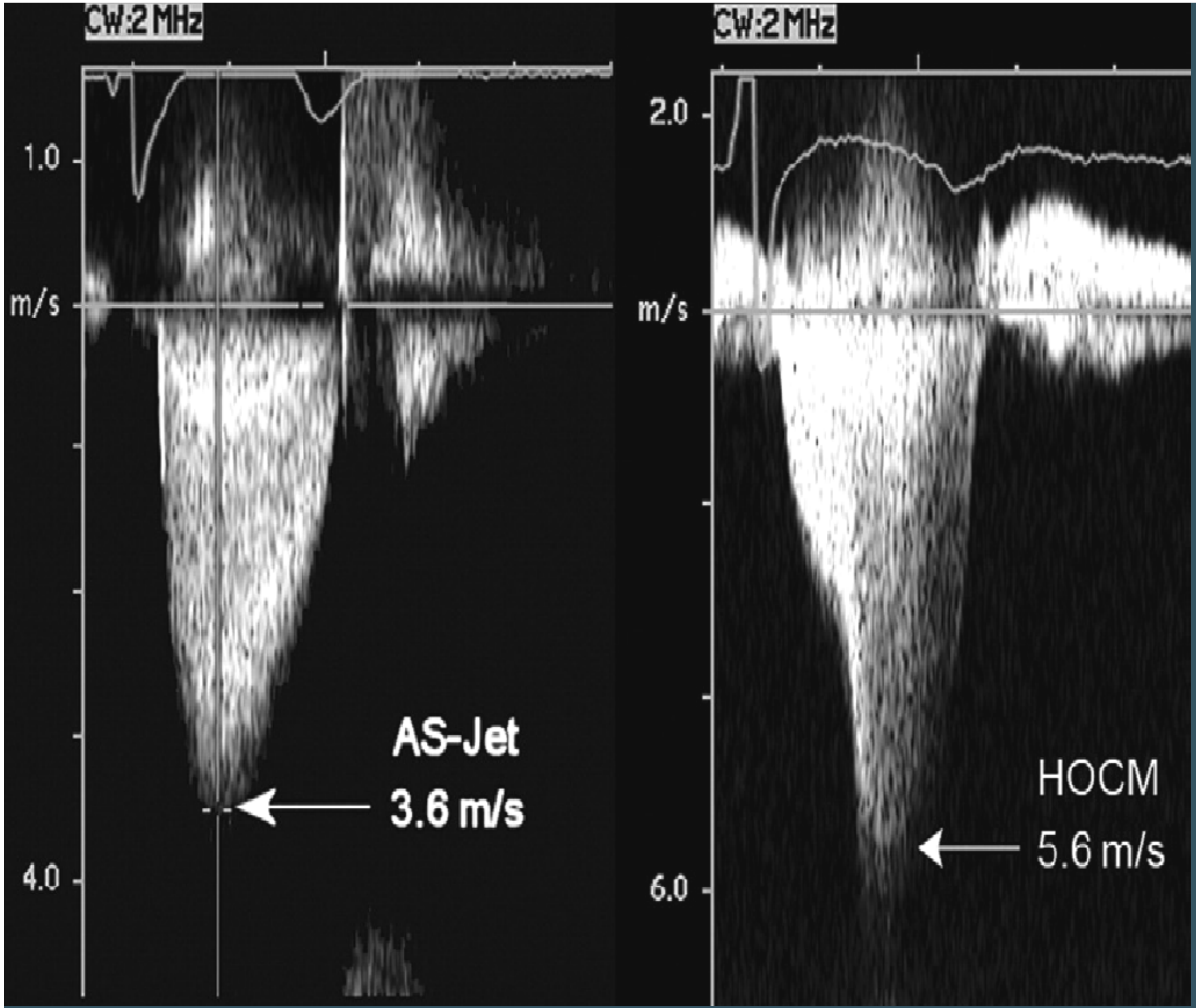

Figure 3 An example of moderate aortic stenosis (left) and dynamic outflow obstruction in hypertrophic cardiomyopathy (right). Note the different shapes of the velocity curves and the later maximum velocity with dynamic obstruction

Figure 4 Schematic diagram of continuity equation

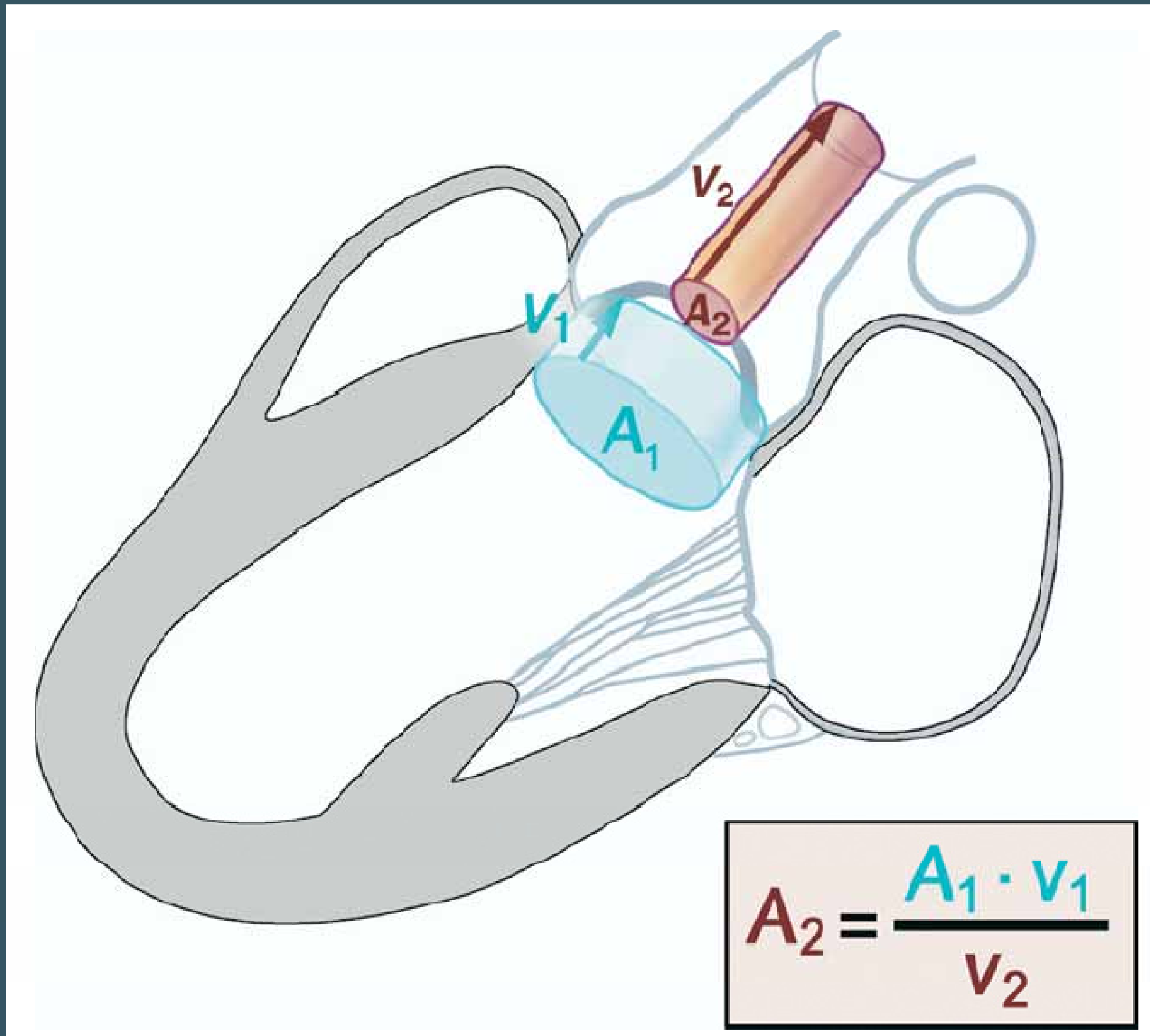

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Figure 5 Left ventricular outflow tract diameter is measured in the parasternal long-axis view in mid-systole from the white–black interface of the septal endocardium to the anterior mitral leaflet, parallel to the aortic valve plane and within 0.5–1.0 cm of the valve orifice

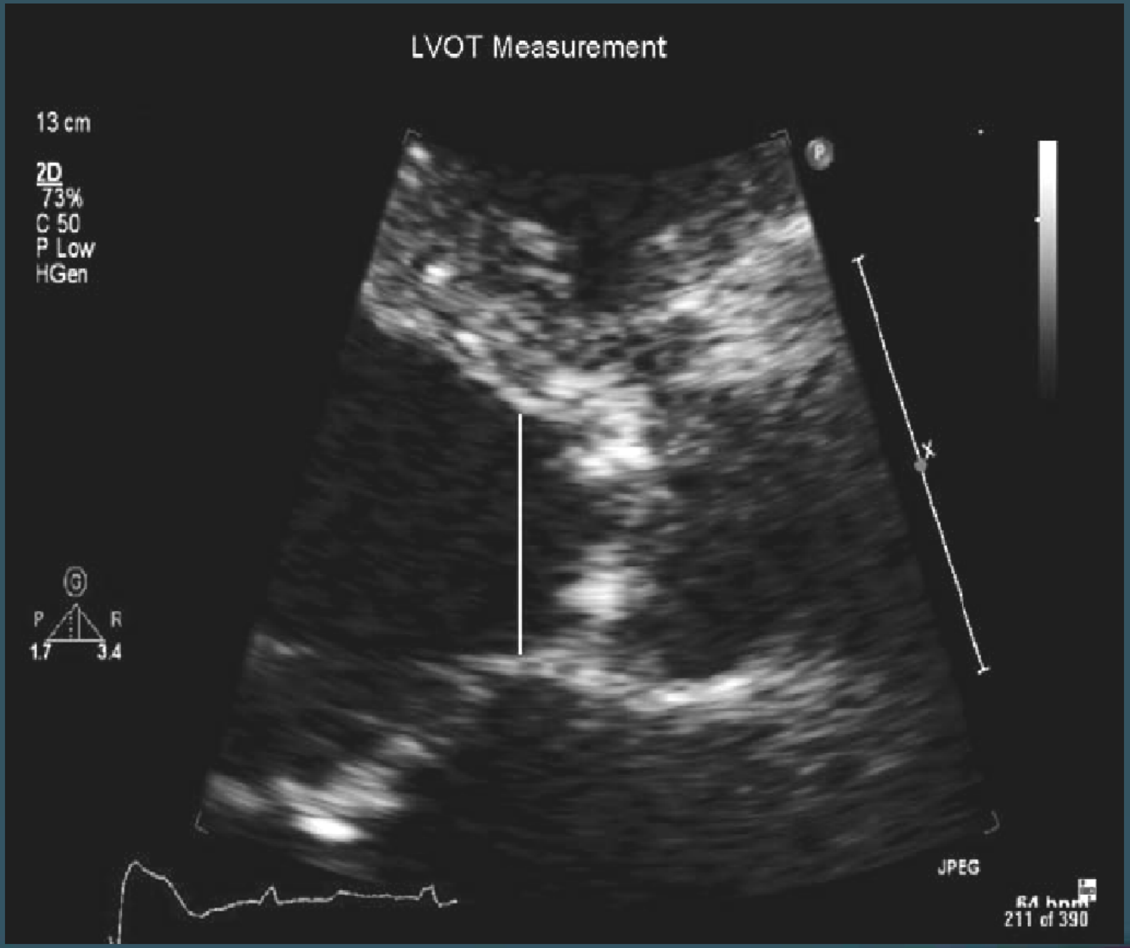

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Figure 6 Left ventricular outflow tract (LVOT) velocity is measured from the apical approach either in an apical long-axis view or an anteriorly angulated four-chamber view (as shown here). Using pulsed-Doppler, the sample volume (SV), with a length (or gate) of 3–5 mm, is positioned on the LV side of the aortic valve, just proximal to the region of flow acceleration into the jet. An optimal signal shows a smooth velocity curve with a narrow velocity range at each time point. Maximum velocity is measured as shown. The VTI is measured by tracing the modal velocity (middle of the dense signal) for use in the continuity equation or calculation of stroke volume

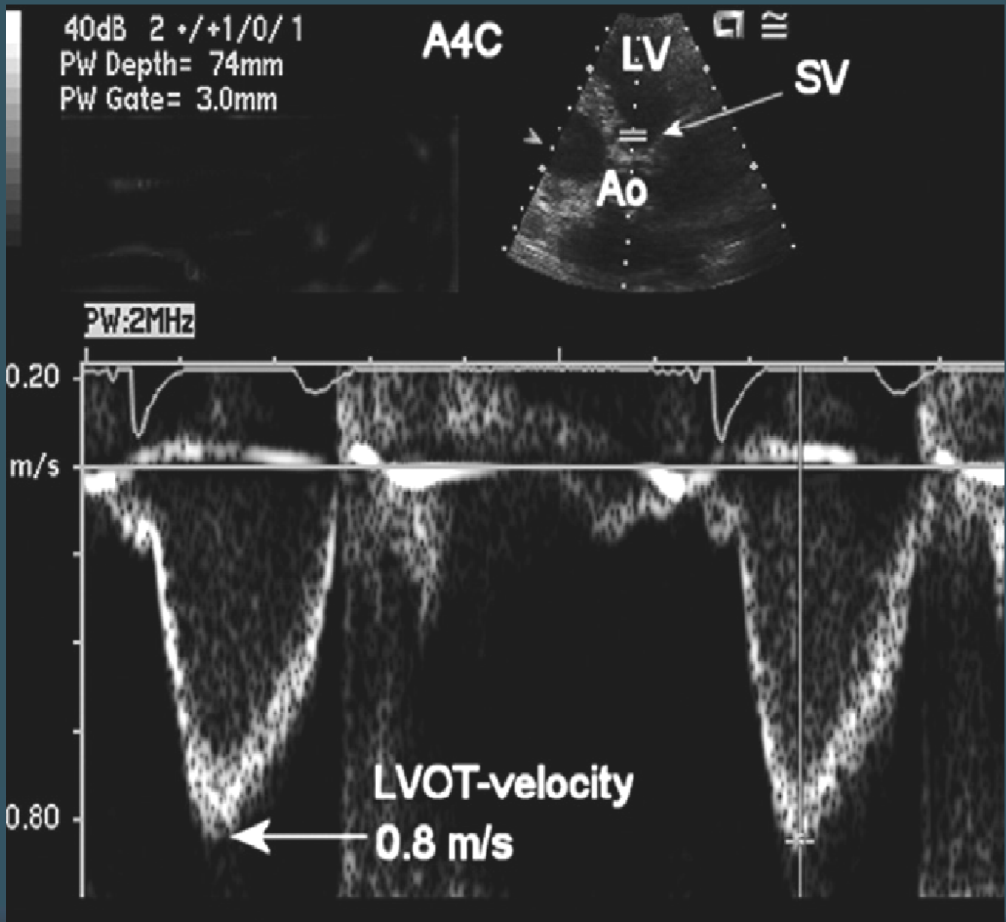

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Table 3 Recommendations for classification of AS severity

	Aortic sclerosis	Mild	Moderate	Severe
Aortic jet velocity (m/s)	≤2.5 m/s	2.6–2.9	3.0–4.0	>4.0
Mean gradient (mmHg)	–	<20 (<30[a])	20–40[b] (30–50[a])	>40[b] (>50[a])
AVA (cm^2)	–	>1.5	1.0–1.5	<1.0
Indexed AVA (cm^2/m^2)		>0.85	0.60–0.85	<0.6
Velocity ratio		>0.50	0.25–0.50	<0.25

[a]ESC Guidelines.
[b]AHA/ACC Guidelines.

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Table 4 Resolution of apparent discrepancies in measures of AS severity

AS velocity >4 m/s and AVA >1.0 cm^2

1. Check LVOT diameter measurement and compare with previous studies[a]
2. Check LVOT velocity signal for flow acceleration
3. Calculate indexed AVA when
   a. Height is <135 cm (5′5″)
   b. BSA <1.5 m^2
   c. BMI <22 (equivalent to 55 kg or 120 lb at this height).
4. Evaluate AR severity
5. Evaluate for high cardiac output
   a. LVOT stroke volume
   b. 2D LV EF and stroke volume

Likely causes: high output state, moderate–severe AR, large body size

AS velocity ≤4 m/s and AVA ≤1.0 cm^2

1. Check LVOT diameter measurement and compare with previous studies[a]
2. Check LVOT velocity signal for distance from valve
3. Calculate indexed AVA when
   a. Height is <135 cm (5′5″)
   b. BSA <1.5 m^2
   c. BMI <22 (equivalent to 55 kg or 120 lb at this height)
4. Evaluate for low transaortic flow volume
   a. LVOT stroke volume
   b. 2D LV EF and stroke volume
   c. MR severity
   d. Mitral stenosis
5. When EF <55%
   a. Assess degree of valve calcification
   b. Consider dobutamine stress echocardiography

Likely causes: low cardiac output, small body size, severe MR

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Mitral stenosis

Echocardiography plays a major role in decision-making for MS, allowing for confirmation of diagnosis, quantitation of stenosis severity and its consequences, and analysis of valve anatomy.

Indices of Stenosis Severity

- **Pressure gradient.**

The estimation of the diastolic pressure gradient is derived from the transmitral velocity flow curve using the simplified Bernoulli equation. The use of CWD is preferred.

- **MVA Planimetry**

Considered as the reference measurement of MVA. Planimetry measurement is obtained by direct tracing of the mitral orifice, including opened commissures, if applicable, on a parasternal short-axis view. Careful scanning from the apex to the base of the LV is required to ensure that the CSA is measured at the leaflet tips. The measurement plane should be perpendicular to the mitral orifice.

- **Pressure half-time**

T1/2 is defined as the time interval in milliseconds between the maximum mitral gradient in early diastole and the time point where the gradient is half the maximum initial value. MVA is derived using the empirical formula:

MVA = 220 / T1/2

Figure 7 Determination of mean mitral gradient from Doppler diastolic mitral flow in a patient with severe mitral stenosis in atrial fibrillation. Mean gradient varies according to the length of diastole: it is 8 mmHg during a short diastole (A) and 6 mmHg during a longer diastole (B)

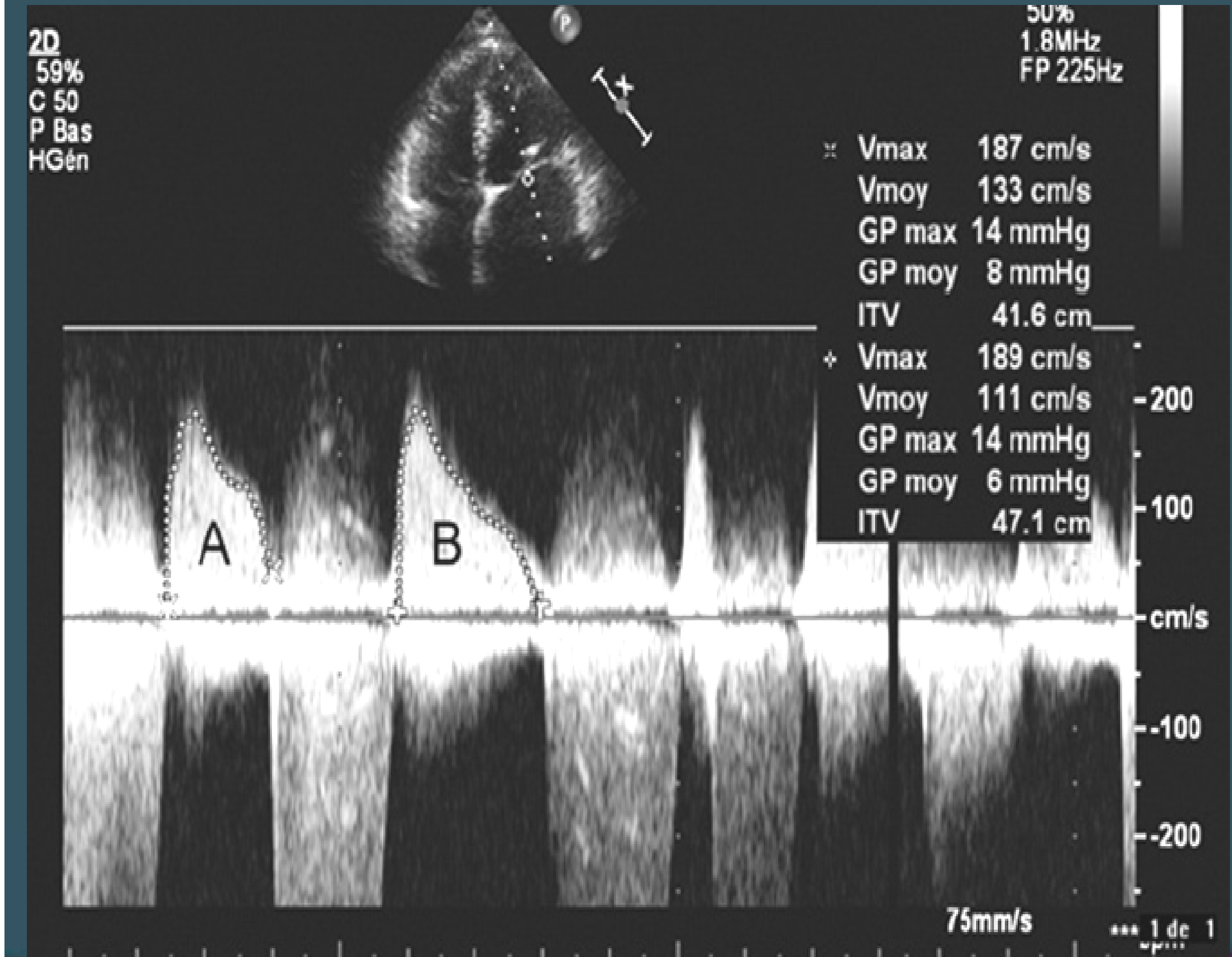

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Figure 8 Planimetry of the mitral orifice. Transthoracic echocardiography, parasternal short-axis view. (A) Mitral stenosis. Both commissures are fused. Valve area is 1.17 cm^2
(B) Unicommissural opening after balloon mitral commissurotomy. The postero-medial commissure is opened. Valve area is 1.82 cm^2. (C) Bicommissural opening after balloon mitral commissurotomy.
Valve area is 2.13 cm^2

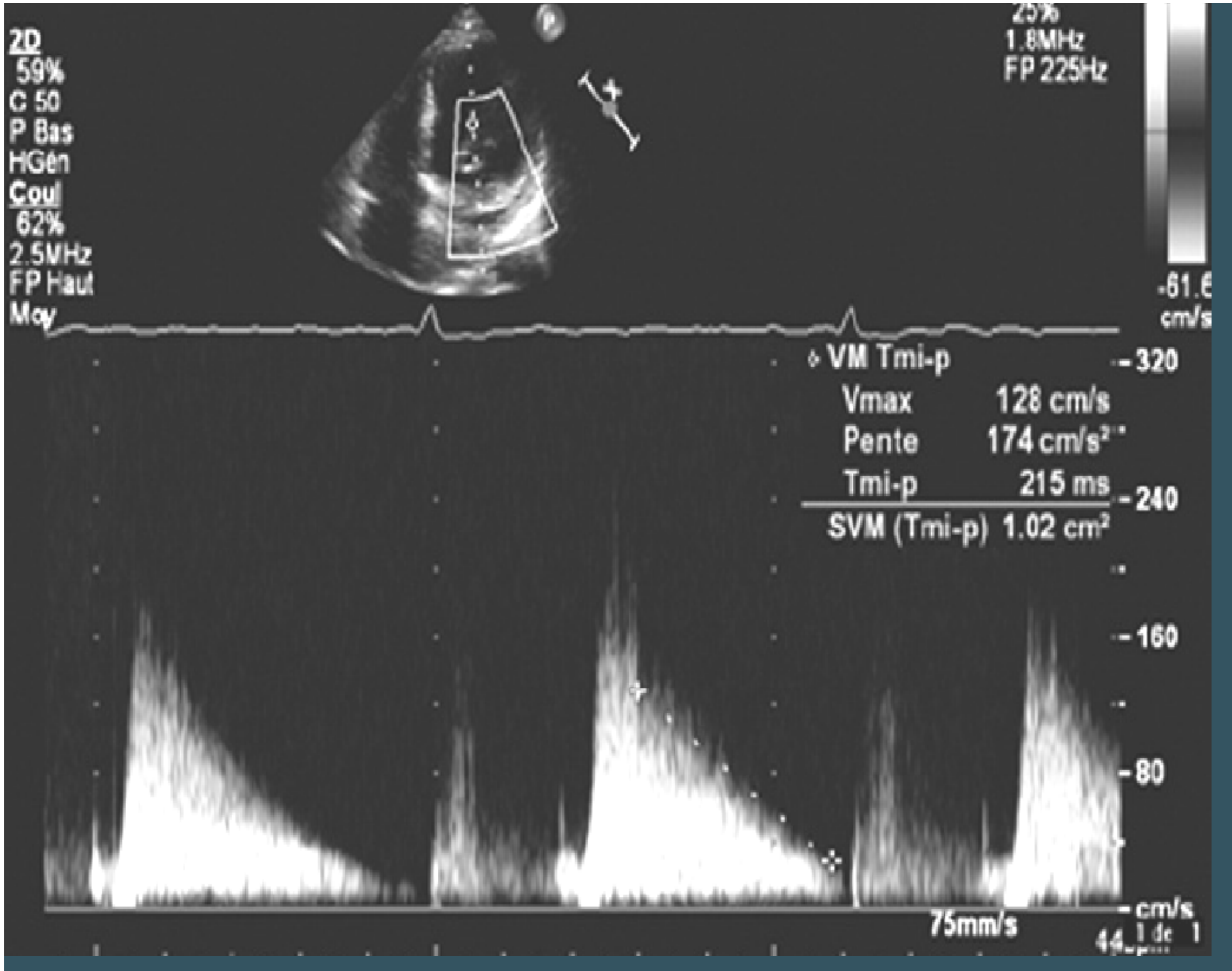

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Figure 9. Estimation of mitral valve area using the pressure half-time method in a patient with mitral stenosis in atrial fibrillation. Valve area is 1.02 cm^2

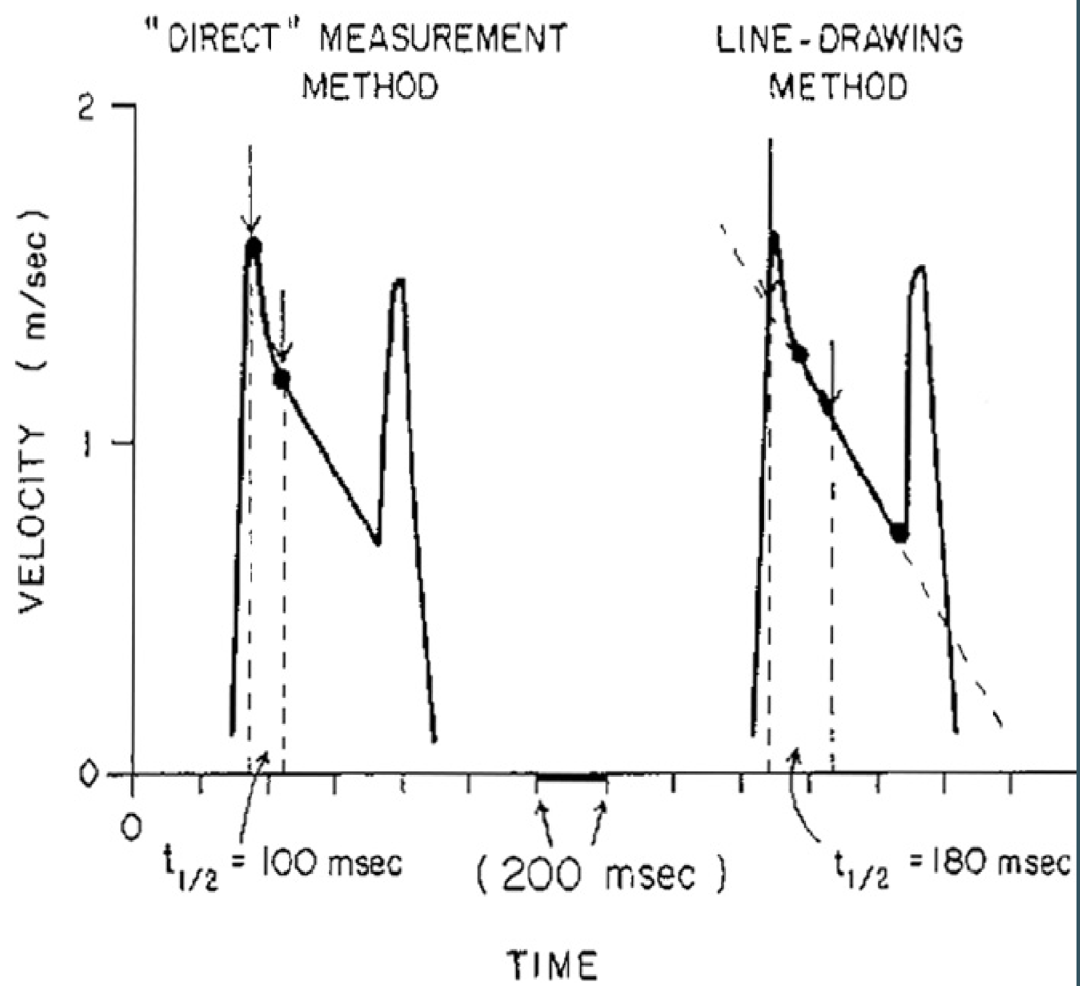

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Figure 10 Determination of Doppler pressure half-time (*T*1/2) with a bimodal, non-linear decreasing slope of the E-wave. The deceleration slope should not be traced from the early part (left), but using the extrapolation of the linear mid-portion of the mitral velocity profile (right).

Reproduced from Gonzalez MA, Child JS, Krivokapich J. Comparison of two-dimensional and Doppler echocardiography and intracardiac hemodynamics for quantification of mitral stenosis. Am J Cardiol 1987;60:327-32

Table 5. Assessment of mitral valve anatomy according to the Wilkins score. The total score is the sum of the four items and ranges between 4 and 16

Grade	Mobility	Thickening	Calcification	Subvalvular Thickening
1	Highly mobile valve with only leaflet tips restricted	Leaflets near normal in thickness (4–5 mm)	A single area of increased echo brightness	Minimal thickening just below the mitral leaflets
2	Leaflet mid and base portions have normal mobility	Midleaflets normal, considerable thickening of margins (5–8 mm)	Scattered areas of brightness confined to leaflet margins	Thickening of chordal structures extending to one-third of the chordal length
3	Valve continues to move forward in diastole, mainly from the base	Thickening extending through the entire leaflet (5–8 mm)	Brightness extending into the mid-portions of the leaflets	Thickening extended to distal third of the chords
4	No or minimal forward movement of the leaflets in diastole	Considerable thickening of all leaflet tissue (>8–10 mm)	Extensive brightness throughout much of the leaflet tissue	Extensive thickening and shortening of all chordal structures extending down to the papillary muscles

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Table 6 Assessment of mitral valve anatomy according to the Cormier score

Echocardiographic group	Mitral valve anatomy
Group 1	Pliable non-calcified anterior mitral leaflet and mild subvalvular disease (i.e. thin chordae ≥10 mm long)
Group 2	Pliable non-calcified anterior mitral leaflet and severe subvalvular disease (i.e. thickened chordae <10 mm long)
Group 3	Calcification of mitral valve of any extent, as assessed by fluoroscopy, whatever the state of subvalvular apparatus

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Table 7 Recommendations for data recording and measurement in routine use for mitral stenosis quantitation

Data element	Recording	Measurement
Planimetry	- 2D parasternal short-axis view - determine the smallest orifice by scanning from apex to base - positioning of measurement plan can be oriented by 3D echo - lowest gain setting to visualize the whole mitral orifice	- contour of the inner mitral orifice - include commissures when opened - in mid-diastole (use cine-loop) - average measurements if atrial fibrillation
Mitral flow	- continuous-wave Doppler - apical windows often suitable (optimize intercept angle) - adjust gain setting to obtain well-defined flow contour	- mean gradient from the traced contour of the diastolic mitral flow - pressure half-time from the descending slope of the E-wave (mid-diastole slope if not linear) - average measurements if atrial fibrillation
Systolic pulmonary artery pressure	- continuous-wave Doppler - multiple acoustic windows to optimize intercept angle	- maximum velocity of tricuspid regurgitant flow - estimation of right atrial pressure according to inferior vena cava diameter
Valve anatomy	- parasternal short-axis view	- valve thickness (maximum and heterogeneity) - commissural fusion - extension and location of localized bright zones (fibrous nodules or calcification)
	- parasternal long-axis view	- valve thickness - extension of calcification - valve pliability - subvalvular apparatus (chordal thickening, fusion, or shortening)
	- apical two-chamber view	- subvalvular apparatus (chordal thickening, fusion, or shortening) Detail each component and summarize in a score

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Table 8. Approaches to evaluation of mitral stenosis (Part 1)

Measurement	Units	Formula / Method	Concept	Advantages	Disadvantages
Valve area					
- planimetry by 2D echo	cm^2	tracing mitral orifice using 2D echo	direct measurement of anatomic MVA	- accuracy - independence from other factors	- experience required - not always feasible (poor acoustic window, severe valve calcification)
- pressure half-time	cm^2	$220 / T_{1/2}$	rate of decrease of transmitral flow is inversely proportional to MVA	easy to obtain	dependence on other factors (AR, LA compliance, LV diastolic function...)
- continuity equation	cm^2	$MVA = (CSA_{LVOT})(VTI_{Aortic}) / VTI_{Mitral}$	volume flows through mitral and aortic orifices are equal	independence from flow conditions	- multiple measurements (sources of errors) - not valid if significant AR or MR
- PISA	cm^2	$MVA = \pi(r^2)(V_{aliasing}) / \text{peak } V_{Mitral} \cdot \alpha/180°$	MVA assessed by dividing mitral volume flow by the maximum velocity of diastolic mitral flow	independence from flow conditions	technically difficult
Mean gradient	mm Hg	$\Delta P = \sum 4v^2 / N$	pressure gradient calculated from velocity using the Bernoulli equation	easy to obtain	dependent on heart rate and flow conditions
Systolic pulmonary artery pressure	mm Hg	$sPAP = 4v^2_{Tricuspid} + \text{RA pressure}$	addition of RA pressure and maximum gradient between RV and RA	obtained in most patients with MS	- arbitrary estimation of RA pressure - no estimation of pulmonary vascular resistance

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Table 8. Approaches to evaluation of mitral stenosis (Part 2)

Measurement	Units	Formula / Method	Concept	Advantages	Disadvantages
Mean gradient and systolic pulmonary artery pressure at exercise	mm Hg	$\Delta P = \sum 4v^2 / N$ $sPAP = 4v^2_{Tricuspid}$ + RA pressure	assessment of gradient and sPAP for increasing workload	incremental value in assessment of tolerance	- experience required - lack of validation for decision-making
Valve resistance	$dyne.sec^{-1}cm^{-5}$	$Mvres = \bar{P}_{Mitral} / (CSA_{LVOT})(VTI_{Aortic}) / DFT)$	resistance to flow caused by MS	initially suggested to be less flow-dependent, but not confirmed	no prognostic value no clear threshold for severity no additional value vs. valve area

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Level of recommendations: (1) appropriate in all patients (yellow); (2) reasonable when additional information is needed in selected patients (green);and (3) not recommended (blue).

AR, Aortic regurgitation; CSA, cross-sectional area; DFT, diastolic filling time; LA, left atrium; LV, left ventricle; LVOT, left ventricular outflow tract;MR, mitral regurgitation; MS, mitral stenosis; MVA, mitral valve area; MVres, mitral valve resistance; *P*, gradient; sPAP, systolic pulmonary artery pressure; *r*, the radius of the convergence hemisphere; RA, right atrium; RV, right ventricle; *T*1/2, pressure half-time; *v*, velocity; VTI, velocity time integral; N, number of instantaneous measurements.

Table 9. Recommendations for classification of mitral stenosis severity

	Mild	Moderate	Severe
Specific findings			
Valve area (cm^2)	>1.5	1.0–1.5	<1.0
Supportive findings			
Mean gradient (mmHg)[a]	<5	5–10	>10
Pulmonary artery pressure (mmHg)	<30	30–50	>50

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[a]At heart rates between 60 and 80 bpm and in sinus rhythm.

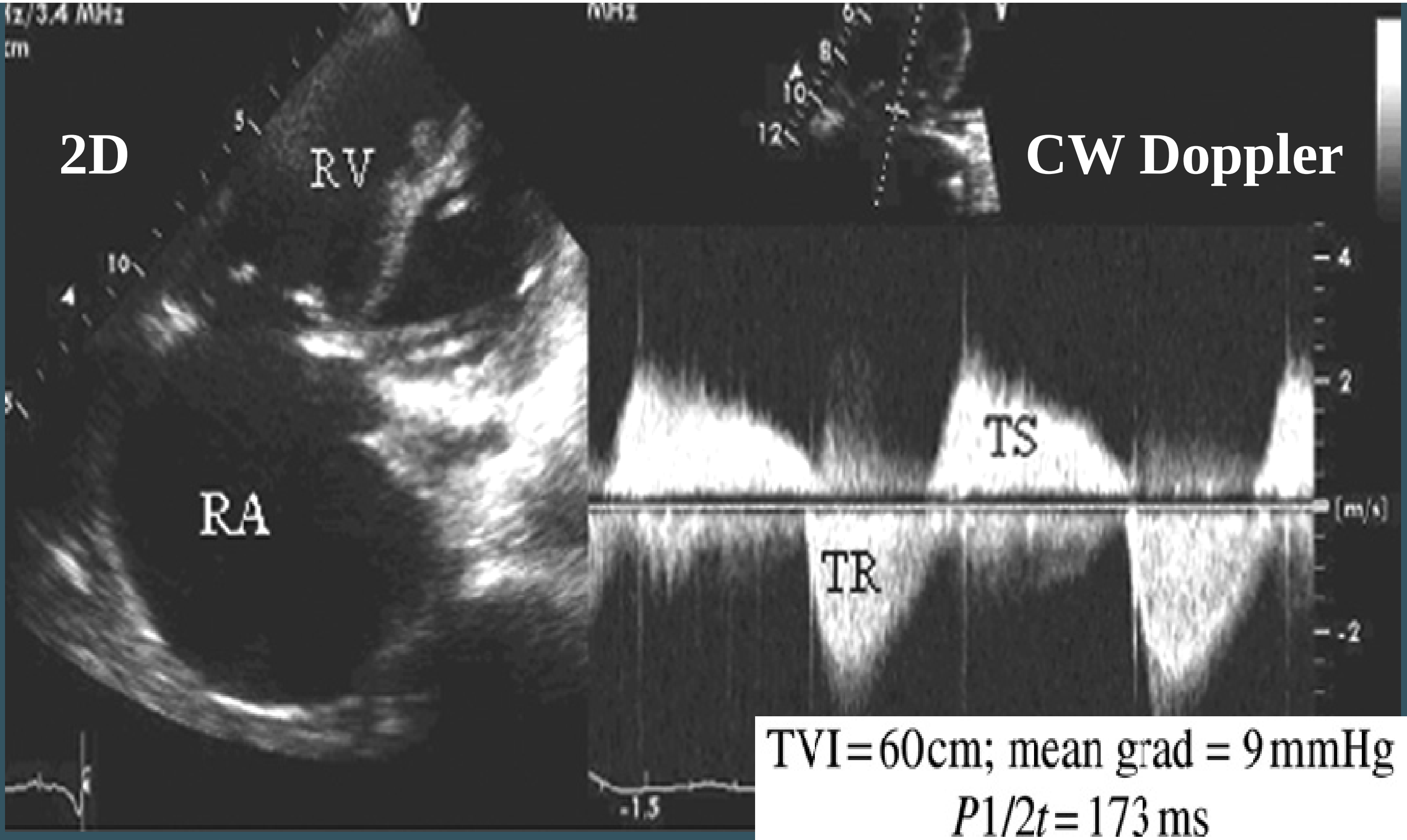

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Figure 11. The left panel illustrates a 2D echocardiographic image of a stenotic tricuspid valve obtained in a modified apical four-chamber view during diastole. Note the thickening and diastolic doming of the valve, and the marked enlargement of the right atrium (RA). The right panel shows a CW Doppler recording through the tricuspid valve. Note the elevated peak diastolic velocity of 2 m/s and the systolic tricuspid regurgitation (TR) recording. The diastolic time–velocity integral (TVI), mean gradient (Grad), and pressure half-time (*T*1/2) values are listed.

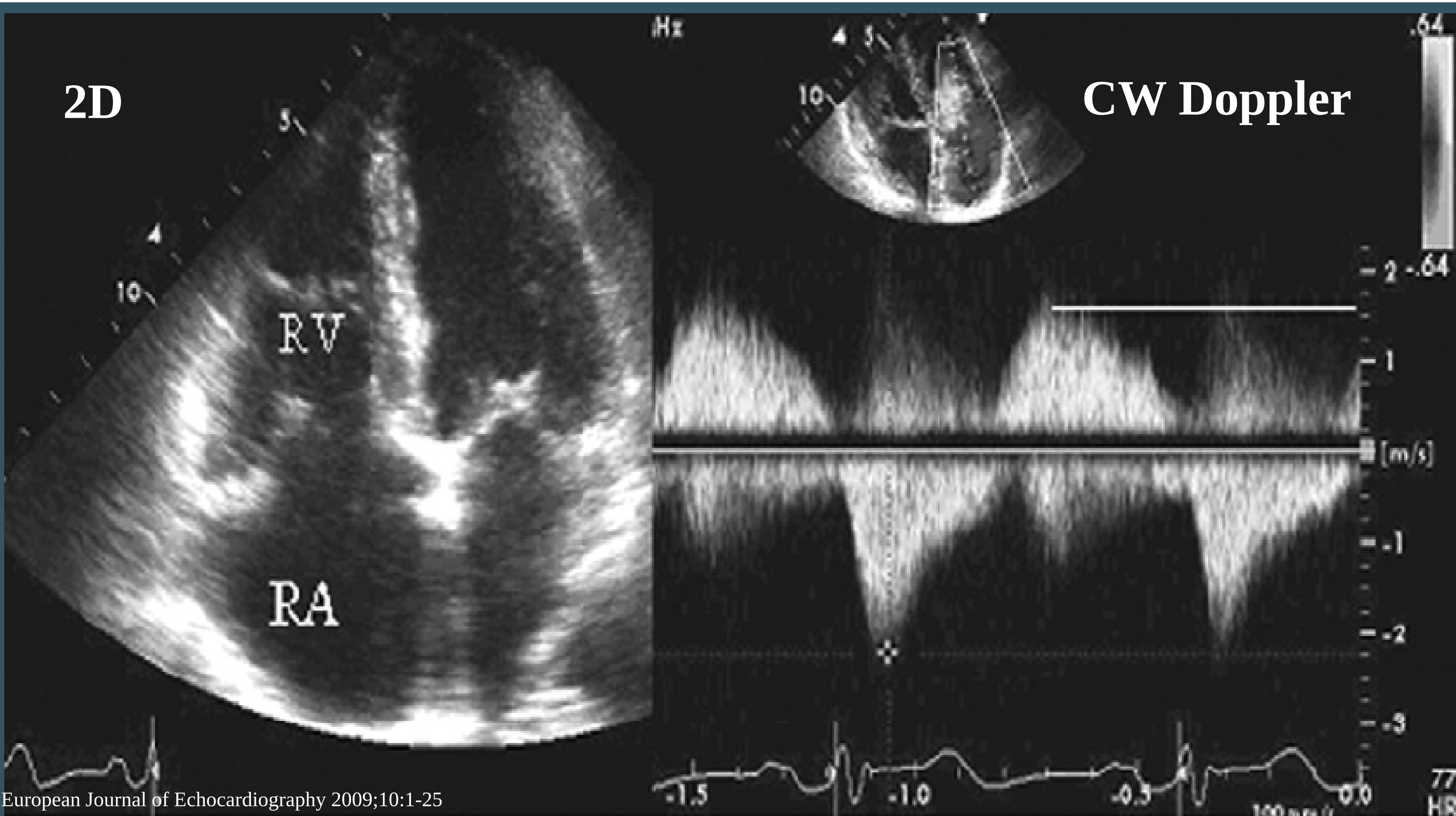

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Figure 12 The left panel illustrates a 2D echocardiographic image of a tricuspid valve in a patient with carcinoid syndrome, obtained in an apical four-chamber view during systole. Note the thickening and opened appearance of the valve. The right panel shows a continuous-wave Doppler recording through the tricuspid valve. Note an elevated peak diastolic velocity of 1.6 m/s and the systolic TR recording.

Table 10. Findings indicative of haemodynamically significant tricuspid stenosis

Specific findings	
Mean pressure gradient	$\geq$5 mmHg
Inflow time–velocity integral	>60 cm
$T_{1/2}$	$\geq$190 ms
Valve area by continuity equation[a]	$\leq$1 cm^{2}[a]
Supportive findings	
Enlarged right atrium $\geq$moderate	
Dilated inferior vena cava	

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[a]Stroke volume derived from left or right ventricular outflow. In the presence of more than mild TR, the derived valve area will be underestimated. Nevertheless, a value 1 cm^2 implies a significant haemodynamic burden imposed by the combined lesion.

Table 11. Grading of pulmonary stenosis

	Mild	Moderate	Severe
Peak velocity (m/s)	<3	3–4	>4
Peak gradient (mmHg)	<36	36–64	>64

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