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sc0020

109 Quantification of Mitral Stenosis

Muhamed Saric, MD, PhD, Roberto M. Lang, MD, and Itzhak Kronzon, MD

p0400 Echocardiography is the modality of choice for the diagnosis of mitral stenosis. The joint American Society of Echocardiography and European Association of Echocardiography guidelines for native valvular stenosis feature an exhaustive review of echocardiographic methods for quantitative assessment of mitral stenosis.[1] Full echocardiographic evaluation of mitral stenosis includes the following three sets of parameters: (1) mean diastolic transmitral pressure gradient; (2) mitral valve area (MVA); and (3) secondary changes including measurements of relevant chamber sizes and estimation of right heart pressures. Most modern ultrasound systems contain built-in software packages for determining these parameters. Major methods for quantification of mitral stenosis are presented in Figures 109-1 and 109-2. In most instances, evaluation of mitral stenosis by invasive methods of cardiac catheterization is not necessary unless there is a discrepancy between clinical and echocardiographic findings.

s0070 MEAN PRESSURE GRADIENT MEASUREMENTS

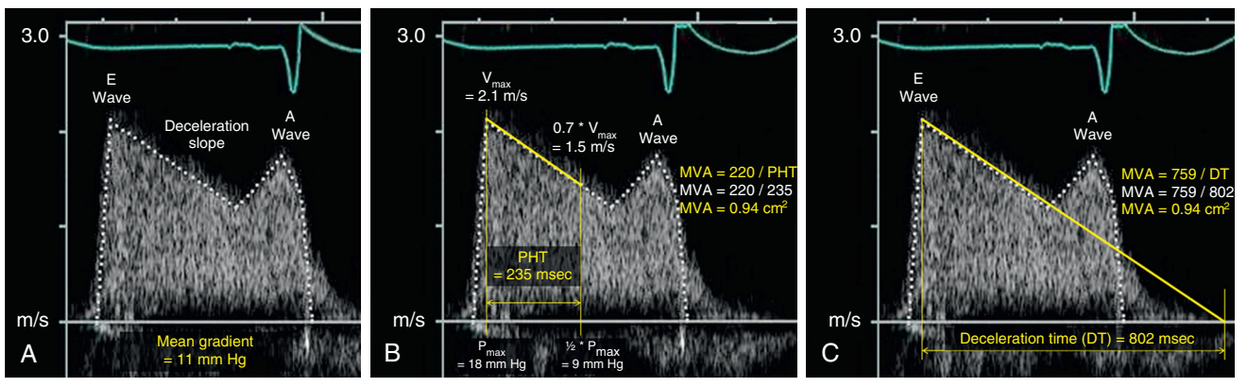
p0405 Mean diastolic pressure gradient is inversely related to MVA; that is, the more severe the mitral stenosis, the higher the mean diastolic pressure gradient across the mitral valve. This gradient can be easily measured by pulsed- and continuous-wave Doppler.[2] The best approach for transmitral flow evaluation and gradient determination should be with the transducer at the apex, imaging in four-chamber or two-chamber views. Color flow imaging can be helpful for the assessment of the exact direction of the transmitral flow. The angle between the interrogating beam and the transmitral jet should be 0 degrees.

Gradient can be assessed by pulsed-wave Doppler with the sample volume at the tips of the leaflets or by continuous-wave Doppler. By tracing the spectral Doppler-derived diastolic transmitral flow velocity envelope and with the use of built-in algorithms available in most modern ultrasound imaging systems, one can obtain the mean MV gradient (see Fig. 109-1, *A*). To calculate the mean gradient, the system first calculates instantaneous pressure gradients using the simplified Bernoulli equation (see Eq. 109-4, later) and then averages them out: p0410

$$\Delta P = \frac{\sum_{i=0}^{n} Vi^2}{n} \qquad (109\text{-}1)$$

where ΔP is the mean diastolic transmitral pressure gradient, V is the instantaneous transmitral velocity, and n is the number of instantaneous gradients measured.

In the presence of atrial fibrillation, mean diastolic gradient should be averaged from multiple (typically five) cardiac cycles. When the mitral valve is normal, there is no significant diastolic transmitral pressure gradient. In severe mitral stenosis, the mean gradient is typically greater than 10 mm Hg; in moderate stenosis it is between 5 and 10 mm Hg, and in mild stenosis it is less than 5 mm Hg. It is important to emphasize that these cutoff values assume a normal transmitral flow (a normal stroke volume and a p0420



f0040 **Figure 109-1.** Quantitative assessment of mitral stenosis by spectral Doppler. **A,** Assessment of the mean diastolic mitral gradient. This patient has severe mitral stenosis (mean gradient 11 mm Hg at a heart rate of 70 beats per minute). **B,** Mitral valve area by pressure half-time *(PHT)*. This patient has severe mitral stenosis (mitral valve area 0.94 cm^2). Note that a 50% drop in initial pressure (from 18 to 9 mm Hg) corresponds to a 70% drop in initial velocity (from 2.1 m/sec to 1.5 m/sec). (See Video 109-1, *B*, which conceptually corresponds to this panel, albeit in a different patient.) **C,** Mitral valve area by deceleration time *(DT)*. Because DT is approximately 0.29 × PHT, the formula MVA = 220/PHT may be expressed as MVA = 759/DT.

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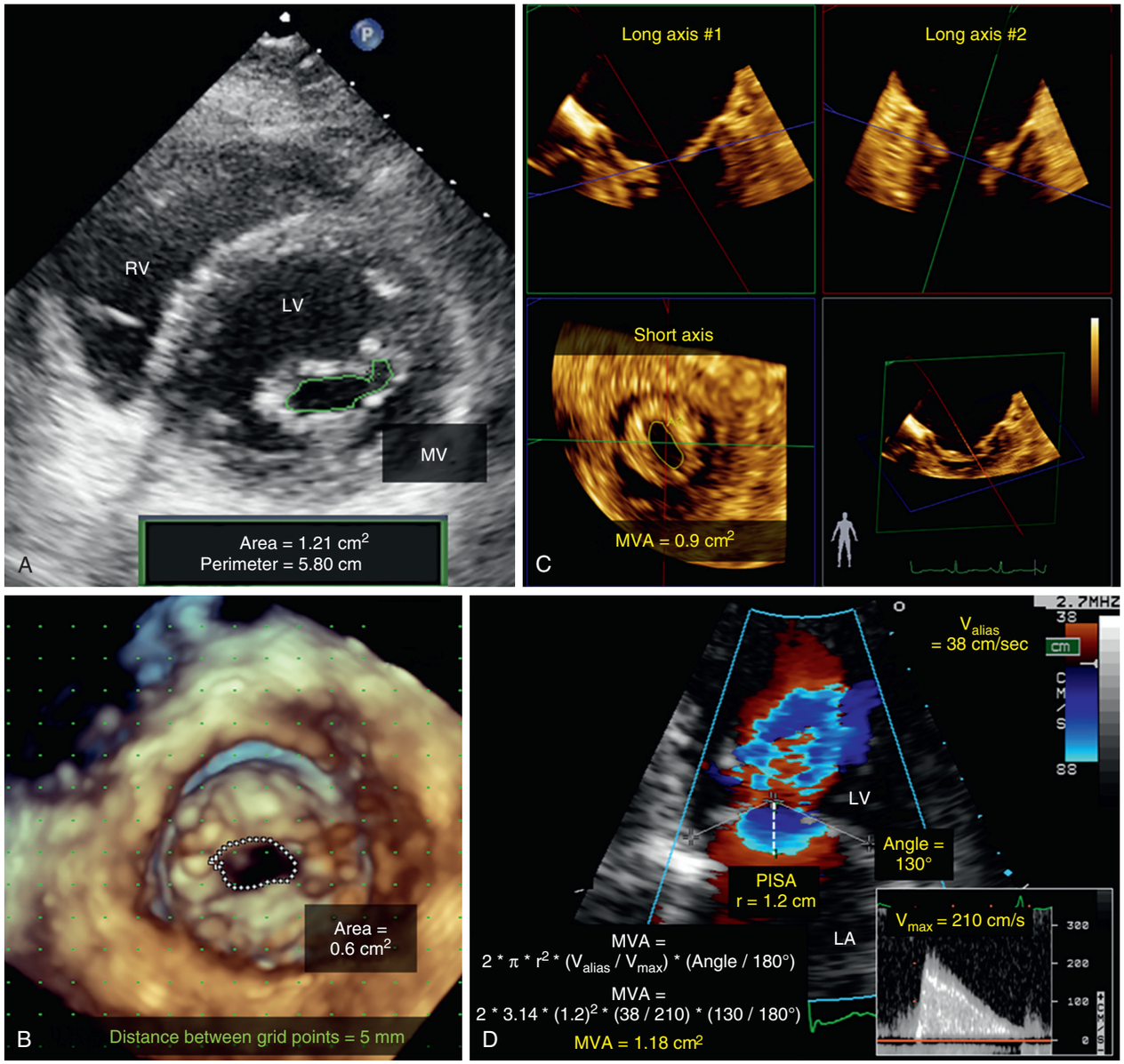

f0045 **Figure 109-2.** Quantitative assessment of mitral stenosis by mitral valve area (MVA) methods. **A,** Mitral valve area by two-dimensional planimetry at mitral leaflet tips in the transthoracic short axis. The patient has mild moderate mitral stenosis (MVA = 1.21 cm^2) (see Video 109-2, *A*). **B,** Mitral valve area by three-dimensional (3D) planimetry in this patient with severe mitral stenosis. The panel demonstrates the LV aspect of the mitral valve. On newer systems, MVA can be planimetered directly on a 3D image (0.6 cm^2 in this patient). On older systems, a grid is used to calculate MVA. Each rectangle on the grid corresponds to 0.25 cm^2 (5 × 5 mm) (see Video 109-2b). **C,** Mitral valve area by multiplane reconstruction (MPR) of a 3D transesophageal echocardiography clip. MPR allows for localizing true tips of mitral leaflets; thus this method allows for most accurate assessment of anatomic mitral valve area. **D,** Mitral valve area by proximal isovelocity surface area (PISA) method. Both color and continuous-wave spectral Doppler are required. Note that when the color Doppler baseline is shifted, the aliasing velocity used to calculate MVA is the one in the direction of blood flow (38 cm/sec in this case). This patient has moderate mitral stenosis (MVA = 1.12 cm^2). *LA,* Left atrium; *LV,* left ventricle; *MV,* mitral valve; *RA,* right atrium.

normal heart rate). Mean diastolic gradient is strongly influenced by changes in transmitral flow:

$$\Delta P \approx Flow^2 \qquad (109\text{-}2)$$

p0425 Thus, exercise, fever, anemia, and/or pregnancy may lead to marked increases in transmitral pressure gradients and worsening of patients' symptoms. For instance, during pregnancy, cardiac output may increase 1.7-fold; based on Equation 109-2, this theoretically translates to a 1.7^2 or 2.9-fold increase in transmitral pressure gradient.[3]

p0430 Stress testing may provide additional information on hemodynamic significance of mitral stenosis; transmitral pressure gradients and right heart pressures are measured during exercise or dobutamine stress echocardiography. Stress testing in mitral stenosis may be used to assess patients' symptoms or to evaluate for percutaneous mitral balloon valvuloplasty (PMBV). For instance, in asymptomatic patients with moderate or severe mitral stenosis,

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TABLE 109-1 Quantitative Assessment of Mitral Stenosis TS1

	Parameter	Unit	Normal	Mild MS	Moderate MS	Severe MS	Method	Comments
Primary determinantof severity	Mitral valve area (MVA)	cm^2	4.0-6.0	>1.5	1.0-1.5	<1.0	Planimetry	Possibly the gold standard
							Pressure half-time (PHT)	MVA underestimated: atrial septal defect or severe aortic regurgitation MVA overestimated: LV diastolic dysfunction with low LV compliance
							Proximal isovelocity surface area (PISA)	Typically requires angle correction
							Continuity equation	Not applicable with significant concomitant mitral regurgitation
Supportive findings	Mean gradient	mm Hg	Negligible	<5	5-10	>10	Mean gradient = average of $4V^2$ measurements	Assuming a heart rate of 60-80 bpm. Mean gradient is directly proportional to heart rate and transvalvular flow
	Pulmonary artery systolic pressure (PASP)	mm Hg	<30	<30	30-50	>50	PASP = $4V^2$ + RAP	Caveat: A wide range of PASP has been observed for any given MVA

bpm, Beats per minute; *LV,* left ventricle; *MS,* mitral stenosis; *RAP,* right atrial pressure.

PMBV is indicated when pulmonary artery systolic pressure is greater than 50 mm Hg at rest or greater than 60 mm Hg with exercise, or when there is new-onset atrial fibrillation. PMBV may also be considered in symptomatic patients with mild mitral stenosis (valve area > 1.5 cm^2) when pulmonary artery systolic pressure is greater than 60 mm Hg, pulmonary artery wedge pressure is greater than 25 mm Hg, or mean mitral valve gradient is greater than 15 mm Hg during exercise.[4]

p0435 Unlike the mean gradient, the peak diastolic mitral gradient is not a good measure of mitral stenosis severity, as it is often markedly influenced by other factors such as the left atrial (LA) compliance and left ventricular (LV) diastolic function.

s0075 MITRAL VALVE AREA MEASUREMENTS

p0440 Normal MVA in an adult is approximately 4.0 to 6.0 cm^2. MVA can be calculated using a variety of noninvasive and invasive methods, none of which is considered a true gold standard. Irrespective of the method used, severe mitral stenosis is defined as MVA less than 1.0 cm^2; moderate when MVA is between 1.0 and 1.5 cm^2, and mild when MVA is greater than 1.5 cm^2. Indexing of MVA for body surface area has not been validated.

p0445 The most commonly used invasive method for estimated MVA is based on the Gorlin and Gorlin equation[5] published in 1951:

$$MVA = \frac{Q}{44.3 * c * \sqrt{\Delta P}} \quad (109\text{-}3)$$

where Q is the diastolic transmitral flow rate (in mL/min), c is a constant (0.85 for mitral valve), and ΔP is the mean diastolic transmitral gradient (in mm Hg). This method requires invasive measurements of both the cardiac output and the diastolic transmitral pressure gradient.

p0455 Ideally, the gradient should be measured directly as the difference between LV and LA diastolic pressure, typically after a transseptal puncture. However, pulmonary artery wedge pressure is often used in lieu of LA pressure; this typically overestimates the transmitral gradient (and thus the severity of mitral stenosis) compared with direct LA pressure measurements.[6] Using echocardiography, MVA can either be measured directly (anatomic orifice area) or estimated from Doppler measurements (effective orifice area).

Pressure Half-Time Method s0080

Pressure half-time (PHT) is defined as the length of time required p0460 for the maximal early diastolic transmitral gradient to reach half its value (see Fig. 109-1, *B*, and Video 109-1, *B*). PHT is inversely related to MVA. PHT is quite short in patients without significant mitral stenosis because the transmitral (LA to LV) diastolic pressure gradient declines rapidly as the pressures in these two chambers quickly equalize. On the other hand, with severe mitral stenosis, the pressure gradient declines very slowly, resulting in a long PHT.

A semiquantitative method for estimating MVA from PHT was p0465 originally a cardiac catheterization technique using direct pressure measurements (thus the PHT name).[7] The technique was later adapted for quantitative MVA assessments from noninvasive Doppler measurements. Historically, spectral Doppler was first used to measure PHT; continuous-wave Doppler is now preferred.

Using the simplified Bernoulli equation: p0470

$$\Delta P = 4 * V^2 \quad (109\text{-}4)$$

where ΔP is the transmitral gradient (in mm Hg) and V is the velocity of blood (in m/sec), one can demonstrate that PHT is reached when the initial maximal velocity of blood across the mitral valve during diastole drops to 70% of its initial value. Hatle and colleagues[8] developed an empirical equation for calculating MVA from PHT:

$$\text{MVA } (cm^2) = 220/\text{PHT (msec)} \quad (109\text{-}5)$$

Thus, in a patient with PHT of 220 msec, the MVA is calculated p0480 to be 1.0 cm^2. Because of its simplicity, PHT is the most commonly used Doppler technique for estimating MVA. For patients in atrial fibrillation, an average value of PHT derived from (typically) five cardiac cycles should be used. Short cardiac cycles should be avoided as they may be too brief for the pressure to drop to half its value. In some instances, the spectral Doppler velocity decay has not one but two slopes; this may be seen in patients with both mitral stenosis and mitral regurgitation. In such instances the initial slope (occurring typically within first 300 msec of transmitral flow) can be ignored; subsequent (mid-diastolic) slope should then be used to measure PHT.[9]

Occasionally, the PHT method may not accurately calculate p0485 MVA (e.g., when the changes in LA and/or LV pressures are

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independent of mitral stenosis, when the initial transmitral pressure gradient is very high, or after PMBV).[10] The PHT method overestimates MVA in patients with large atrial septal defects, significant aortic regurgitation, or LV diastolic dysfunction, and/or when the initial transmitral pressure gradient is very high. In patients with both mitral stenosis and atrial septal defect (referred to as Lutembacher syndrome),[11] a significant left-to-right shunt decompresses the leaf atrium, decreases the transmitral gradient, and shortens the PHT, leading to overestimation of MVA. Significant aortic regurgitation and/or LV diastolic dysfunction may lead to increased LV diastolic pressure; this in turn diminishes the transmitral gradient, shortens the PHT, and leads to overestimation of MVA.

p0490 In patients with LV diastolic dysfunction (who tend to be elderly), abnormal LV relaxation leads to either prolongation or shortening of PHT independent of mitral stenosis. Abnormal LV relaxation prolongs PHT (leading to underestimation of MVA), whereas abnormal LV compliance shortens PHT (leading to overestimation of MVA). Thus, the PHT method should be used with caution in elderly patients with mitral stenosis. One should not use PHT to estimate MVA after PMBV because LV diastolic pressure may rise significantly as the relatively noncompliant left ventricle experiences an abrupt increase in transmitral flow after balloon-mediated relief of mitral stenosis.[12] When PHT is unavailable, one can use mitral deceleration time instead.

s0085 Mitral Deceleration Time Method

p0495 The deceleration time (DT) of the mitral E wave is defined as the length of time from the peak velocity of early diastolic mitral flow (E wave Vmax) to the end of antegrade transmitral flow (V = 0). Like PHT, the length of DT is also inversely related to the MVA (i.e., longer DT indicates smaller MVA). Because DT is related to PHT according to

$$\text{PHT (msec)} = 0.29 \times \text{DT (msec)} \quad (109\text{-}6)$$

p0500 MVA can then be calculated from DT (see Fig. 109-1, *C*) from the following equation:

$$\text{MVA (cm}^2\text{)} = 759/\text{DT (msec)} \quad (109\text{-}7)$$

s0090 Mitral Valve Area by Planimetry

p0505 Anatomic MVA can be measured by either two-dimensional (2D) or three-dimensional (3D) planimetry; measurements should be done in mid-diastole at leaflet tips. For 2D planimetry, a short axis at the level of the mitral leaflet tips is obtained and a mid-diastolic frame with maximal opening of mitral leaflets is chosen (see Figure 109-2, *A*, and Video 109-2, *A*). MVA is then planimetered using standard ultrasound-system quantitative tools. The major shortcoming of 2D planimetry is its inability to accurately determine the location of true leaflet tips as they are often eccentrically located outside the short-axis plane.

p0510 3D planimetry overcomes these limitations and is now considered the echocardiographic gold standard for calculation of MVA.[13] 3D planimetry may be done using a variety of methods such as multiplane reconstruction, on-image planimetry, or estimation of MVA using a rectangular reference grid (see Fig. 109-2, *B* and *C*, and Video 109-2, *B*).

s0095 Mitral Valve Area by Doppler Techniques

p0515 Doppler methods for calculated MVA include pressure half-time, continuity equation, and proximal isovelocity surface area (PISA).

Mitral Valve Area by Continuity-Equation Method

s0100 The continuity-equation method assumes that a stroke volume (SV_1) across one orifice equals the stroke volume (SV_2) across another orifice in the same closed circulatory system. In the absence of significant mitral or aortic regurgitation, *diastolic* stroke volume across the mitral valve (MV) is equal to the *systolic* stroke volume across the LV outflow tract (LVOT):

p0520

$$SV_{MV} = SV_{LVOT} \quad (109\text{-}8)$$

Using echocardiography, SV across any orifice can be calculated as a product of the orifice area and the flow velocity time integral (VTI): p0525

$$\text{LVOT Area} * \text{LVOT VTI} = \text{MVA} * \text{MV VTI} \quad (109\text{-}9)$$

Solving for MVA, one obtains the following equation: p0530

$$MVA = LVOT\,Area * \frac{LVOT\,VTI}{MV\,VTI} \quad (109\text{-}10)$$

Systolic LVOT VTI and diastolic MV VTI are measure by pulsed-wave and continuous-wave Doppler, respectively. LVOT area is typically calculated after measuring the systolic LVOT diameter (d) in the parasternal long-axis view and assuming a circular LVOT shape: p0535

$$LVOT\,Area = \pi * \left(\frac{d}{2}\right)^2 \quad (109\text{-}11)$$

Thus, using the continuity equation, MVA can be calculated as follows: p0540

$$MVA = \pi * \left(\frac{d}{2}\right)^2 * \frac{LVOT\,VTI}{MV\,VTI} \quad (109\text{-}12)$$

Aside from significant mitral and aortic regurgitation, a miscalculation of LVOT area is the major limitation of estimating MVA by the continuity-equation method. This occurs because of either mismeasurement of LVOT diameter or frequent noncircularity of LVOT area. In general, the continuity-equation method for estimating MVA should not be used in atrial fibrillation. p0545

Mitral Valve Area by Proximal Isovelocity Surface Area Method

s0105 The PISA method is also based on the continuity principle. The method is described in detail in another chapter. Briefly, blood flow progressively accelerates as it approaches an orifice (such as a stenotic mitral valve). This then ideally leads to formation of a series of hemispheric isovelocity surfaces whose areas become progressively smaller and their velocities progressively faster as the flow approaches the orifice. p0550 Au5

According to the continuity principle, the amount of flow at the level any of the hemispheres should equal the flow across the stenotic mitral valve.[14] Using Doppler methods and the PISA method, MVA area can be calculated using the following formula: p0555

$$MVA = 2 * \pi * r^2 * \frac{Valias}{Vmax} \quad (109\text{-}13)$$

where *r* is the radius of the hemisphere (PISA radius) in centimeters, *Valias* is the aliasing velocity of color Doppler flow (in cm/sec), and *Vmax* is the maximal transmitral velocity (also in cm/sec).

The basic PISA method assumes that the orifice is a planar structure (that is, at a 180-degree angle). Typically, this is not the case with mitral stenosis, where the orifice is funnel shaped (that is, at an angle that is less than 180 degrees). Consequently, p0565

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as the flow approaches a stenosed mitral orifice, PISA shells are not full hemispheres but partial hemispheres. Thus, to properly calculate MVA by the PISA method, Equation 109-13 needs to be modified to include an angle correction factor:

$$MVA = 2 * \pi * r^2 * \frac{Valias}{Vmax} * \frac{\vartheta}{180} \qquad (109\text{-}14)$$

where ϑ is the angle between the two mitral leaflets in diastole (see Fig. 109-2, *D*).

p0575 The PISA method for MVA calculation is valid even in the presence of concomitant mitral regurgitation because increased diastolic flow due to mitral regurgitation will equally affect the flow at the level of both isovelocity hemispheres and mitral leaflet tips.

s0110 Semiquantitative Mitral Valve Area Assessment by M-Mode Echocardiography

p0580 M-mode echocardiography has high sensitivity and specificity for the diagnosis of mitral stenosis. It may demonstrate thickened, calcified, and abnormally moving mitral leaflets. The smaller posterior leaflet, which is fused with the larger anterior leaflet, demonstrates an abnormal anterior motion on M-mode during diastole.

p0585 The severity of mitral stenosis can be roughly estimated from the EF slope of the anterior leaflet. In mitral stenosis, after initial opening (E point), the anterior leaflet does not travel posteriorly toward the closing position fast enough because the elevated transmitral pressure gradient maintains the valve in the opened position longer than normal. The more severe the mitral stenosis, the flatter the EF slope.

p0590 Similarly, the rate of emptying of the left atrium visualized by M-mode can be used to roughly estimate the severity of mitral stenosis. Normally, most atrial emptying (or LV filling) occurs promptly in early diastole, whereas in mitral stenosis LA emptying is gradual and lasts throughout diastole.

s0115 SECONDARY CHANGES DUE TO MITRAL STENOSIS

p0595 Mitral stenosis may lead to chronic LA pressure overload, potentially resulting in LA enlargement, pulmonary hypertension, right heart dilation, and functional tricuspid regurgitation. Techniques for estimating chamber sizes and right heart pressures are discussed in other chapters.

p0600 In patients with mitral stenosis, a wide range of pulmonary artery pressures has been observed for a given MVA. Elevated LA pressure leading to pulmonary venous congestion is the primary reason for pulmonary hypertension in patients with mitral stenosis. For unclear reasons, a subset of patients may also develop pulmonary arterial hypertension, which, unlike pulmonary venous hypertension, may not resolve after percutaneous or surgical correction of mitral stenosis.

p0605 Noninvasive assessment of pulmonary vascular resistance (PVR) by echocardiography may help differentiate between pure pulmonary venous hypertension (normal PVR) and superimposed pulmonary arterial hypertension (high PVR). In general, PVR is directly related to transpulmonary pressure gradient and inversely related to the transpulmonary blood flow. Noninvasively, PVR can be calculated from spectral Doppler tracings of tricuspid regurgitant jet and the flow across the right ventricular outflow tract using the so-called Abbas[15] equation:

$$PVR = 0.16 + 10 * \frac{Vmax\ of\ TR\ Jet}{RVOT\ VTI} \qquad (109\text{-}15)$$

where *Vmax* of the tricuspid regurgitant (TR) jet is in meters per second, right ventricular outflow tract (*RVOT) VTI* in centimeters, and *PVR* in Wood units. In principle, echocardiographic PVR measurements should be confirmed by invasive methods.

p0615 The routine echocardiographic evaluation of MS does not require transesophageal echocardiography (TEE). However, TEE should be considered when the image quality and Doppler information are suboptimal or do not correlate with the clinical impression. TEE is also useful in the evaluation of complications of mitral stenosis, such as LA clot or endocarditis. TEE is also frequently used before and during MV balloon valvuloplasty.[16]

SUMMARY s0120

p0620 The American Society of Echocardiography and European Association of Echocardiography recommend that mean diastolic gradient and MVA determination by planimetry and PHT should performed in all patients with mitral stenosis (Level 1 recommendation). In selected patients, MVA may also be determined by continuity-equation and/or PISA methods (Level 2 recommendation). Stress testing for mitral stenosis is also a Level 2 recommendation. In the presence of significant mitral regurgitation, all the foregoing methods for calculating MVA are valid except for continuity equation. Details of mitral valve anatomy and secondary changes due to mitral stenosis should also be reported for all echocardiographic exams as discussed in relevant chapters of this book.

p0625 Please access ExpertConsult to view the corresponding videos for this chapter.

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