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CME

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Management of Mitral Stenosis Using 2D and 3D Echo-Doppler Imaging

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Management of Mitral Stenosis Using 2D and 3D Echo-Doppler Imaging

Although the prevalence of rheumatic fever is decreasing in developed countries, it still affects numerous areas in the nonindustrialized world. Untreated mitral stenosis (MS) contributes to a significant global morbidity and mortality. Echocardiography is the main diagnostic imaging modality with which to evaluate mitral valve (MV) obstruction and assess the severity and hemodynamic consequences of MS as well as valve morphology. According to current guidelines and recommendations for clinical practice, the severity of MS should not be defined by a single value but assessed by valve areas, mean Doppler gradients, and pulmonary pressures. Transthoracic echocardiography is usually sufficient to grade MS severity and to define the morphology of the valve. Transesophageal echocardiography is used when the valve cannot be adequately assessed with transthoracic echocardiography and to exclude intracardiac thrombi before a percutaneous or surgical intervention. Three-dimensional transthoracic and transesophageal echocardiographic assessment provide more detailed physiological and morphological information. Current definitive treatment for severe MS involves percutaneous mitral balloon valvuloplasty (PMBV) or surgery. The effectiveness of PMBV is related to the etiology of MS, and certain anatomic characteristics tend to predict a more successful outcome for PMBV, whereas other MV structural findings might suggest balloon valvuloplasty to be less likely successful or even contraindicated. (J Am Coll Cardiol Img 2013;6:1191–205) © 2013 by the American College of Cardiology Foundation

Rheumatic fever (RF) is the major cause of mitral stenosis (MS), and although its prevalence has been steadily decreasing in industrialized countries (1,2), rheumatic MS remains the most common heart disease in developing countries (3–5). Globally, there are >15 million cases of rheumatic heart disease, with 233,000 deaths each year and 282,000 new cases per year (6).

Surgical commissurotomy, first described in 1923 (7), became the standard treatment for patients with MS in the late 1940s (8). Since the introduction of the Inoue balloon catheter in 1984 (9), percutaneous mitral balloon valvuloplasty (PMBV) emerged as a safe and effective treatment for MS (10–18) and has evolved as the preferred treatment option for selected symptomatic patients with rheumatic MS (19–21).

The focus of this review is on current 2-dimensional (2D) and 3-dimensional (3D) echocardiographic imaging for the selection of suitable patients for PMBV and on the periprocedural aspects of PMBV.

Rheumatic MS

If the mitral valve (MV) orifice area exceeds 1.5 cm^2, patients are generally asymptomatic at rest (1). The clinical exacerbation of MS occurring with pregnancy or complications such as atrial fibrillation or embolic events (22) confer a poor prognosis if no intervention is performed to correct the MS (1,2,23–25). Commissural fusion is the requisite lesion for PMBV to be effective (Fig. 1). Thus, the effectiveness of PMBV is related to the etiology of MS. RF, the major cause of MS (1,2), results in commissural fusion of the MV, which leads to narrowing of the valve orifice and valve obstruction. In degenerative MS (Fig. 2), generally seen in the elderly or in patients with severe renal disease and secondary hyperparathyroidism, advanced mitral annular calcification is the main lesion and commissural fusion is not present. Other rare causes of MS include congenital MS, as demonstrated in Figure 3, inflammatory diseases, infiltrative diseases, carcinoid heart disease, and drug-induced MS. As with degenerative MS, commissural fusion is rare in these cases; most commonly, the leaflets are thickened and restricted, and, thus, these cases are generally not well suited for PMBV.

Echocardiographic assessment of MS

Echocardiography is the main diagnostic imaging modality to evaluate MV obstruction and to assess the severity and the hemodynamic consequences of MS, as well as valve morphology and extent of the disease (19,20).

Transthoracic echocardiography (TTE) is usually sufficient to grade MS severity and to define the morphology of the MV. Transesophageal echocardiography (TEE) is used when the valve cannot be adequately assessed with TTE and to exclude intracardiac thrombi before a percutaneous or surgical intervention. A 3D TTE and TEE assessment should be incorporated into the routine evaluation of the MV because it provides more detailed physiological and morphological information (26). A stress test should be considered when there is a discrepancy between the resting Doppler echocardiographic measurements and symptoms.

The decision for the method of treatment for the patient and the timing of intervention should be based on functional status, surgical risk, valve anatomy, concomitant diseases, and institutional expertise.

Assessment of MS severity. According to current guidelines and recommendations for clinical practice (19,20,27), the severity of MS should not be defined by a single value but rather be assessed by a multimodality approach that determines valve areas, mean Doppler gradients, and pulmonary pressures (Table 1).

MV AREA. Mitral valve area (MVA) can be assessed by planimetry using either 2D or 3D imaging, pressure half-time (PHT), the continuity equation, and the proximal isovelocity surface area (PISA) method.

The 2D planimetry of the MVA is performed in a parasternal short-axis view at the tip of the leaflets when maximal excursion of the leaflets is seen. The inner edge of the MV orifice is traced in mid-diastole (Fig. 4A). The entire MV orifice should be seen. High gain settings should be avoided as they may lead to underestimation of the MVA. Planimetry has been shown to have the best correlation with anatomic MVA as assessed by explanted valves (28). Two-dimensional planimetry tends to overestimate MVA compared with 3D TEE measurements (Figs. 4B and 4C), especially in patients with a large left atrium (29). As shown in Figure 5, 3D echocardiography provides better alignment of the image plane at the mitral tips, rendering a more accurate and reproducible planimetric measurement with excellent interobserver and intraobserver agreement (29–31).

Complementary to MV planimetry, the MVA can also be derived from Doppler echocardiography using the diastolic PHT method (Fig. 4D) (32). PHT is obtained by tracing the deceleration slope of the E-wave on Doppler spectral display of transmitral inflow. The MVA can be calculated from the following simplified formula: 220/PHT. In case of a bimodal deceleration slope, as shown in Figure 6, it is preferable to trace the deceleration slope in mid-diastole rather than to trace the early deceleration slope (33). In patients with atrial fibrillation, the tracing should be performed in long diastoles and average multiple cardiac cycles. In patients with a concave shape on the Doppler tracing, the method cannot be reliably used. Thomas and Weyman (32) demonstrated that the PHT should vary inversely with the MVA, but also proportionally to net left atrial and ventricular compliance and to the square root of the peak transmitral gradient. Limitations of the PHT method therefore include patients with abnormal left atrial or left ventricular compliance as well as patients with associated aortic regurgitation and atrial septal defects and those who have undergone a previous mitral valvuloplasty (34–38). Sole reliance on PHT to determine the severity of MS should be discouraged.

MS severity can also be assessed by the continuity equation (35) based on the assumption that the filling volume of diastolic mitral flow is equal to aortic stroke volume. The following formula is used:

$$\text{MVA} = \pi\left(\frac{\text{D2}}{4}\right)\left(\frac{\text{VTI aorta (cm)}}{\text{VTI mitral (cm)}}\right)$$

where D is the left ventricular outflow tract diameter and VTI is the velocity time integral.

The accuracy and reproducibility of the method are limited in that the number of measurements needed for this calculation increase the probability of measurement errors. If more than mild mitral or aortic regurgitation is present, the continuity equation will not be accurate and should not be used.

A fourth method for calculation of the MVA is the PISA method, which enables the assessment of mitral flow based on the hemispheric shape of the convergence zone of mitral flow in diastole on the left atrial side as seen by color Doppler. Subsequently, the MVA is calculated by dividing the mitral volume flow by the maximum velocity of mitral flow in diastole, as assessed by continuous-wave Doppler: $\text{MVA} = \pi\,(r^2)(V_{alias})/\text{peak } V_{mitral} \times \alpha/180°$, where r is the radius of the hemispheric convergence zone (in centimeters), V_{alias} is the aliasing velocity (in centimeters per second), peak V_{mitral} is the peak velocity of mitral inflow assessed

ABBREVIATIONS AND ACRONYMS

2D = 2-dimensional
3D = 3-dimensional
IAS = interatrial septum
MR = mitral regurgitation
MS = mitral stenosis
MV = mitral valve
MVA = mitral valve area
PHT = pressure half-time
PISA = proximal isovelocity surface area
PMBV = percutaneous mitral balloon valvuloplasty
RF = rheumatic fever
RT-TT3DE = real-time 3-dimensional transthoracic echocardiography
TEE = transesophageal echocardiography
TTE = transthoracic echocardiography

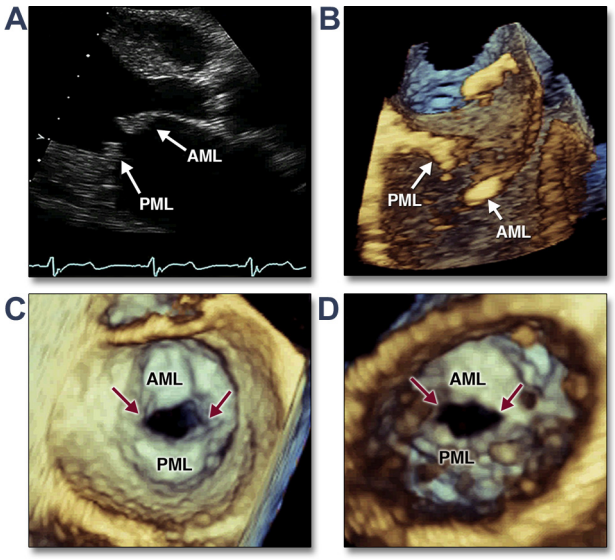

Figure 1. Example of a Typical Rheumatic Mitral Stenosis

(A) Leaflet thickening at the edges is shown in a parasternal long axis transthoracic view. **(B)** The immobility of the posterior leaflet and the doming of the anterior leaflet as typical morphological characteristics of rheumatic mitral valve disease are shown in a 3-dimensional transesophageal image. The 3-dimensional transesophageal images (left atrial aspect **[C]**) and (left ventricular aspect **[D]**) show the fusion of both commissures **(red arrows)**. AML = anterior mitral leaflet; PML = posterior mitral leaflet.

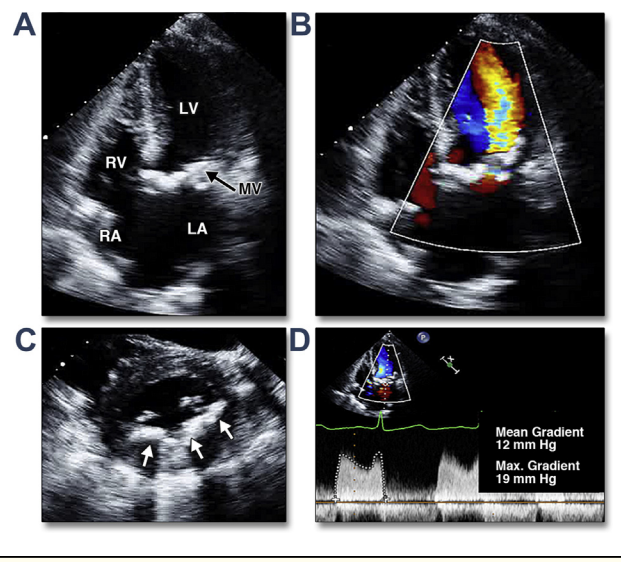

Figure 2. Example of a Degenerative Mitral Stenosis

Severe calcification of the mitral annulus is presented in a 4-chamber view with **(A)** and without **(B)** color Doppler. **(B)** The accelerated mitral inflow through the stenosis is shown. **(C)** A short axis view demonstrates severe calcification of the posterior mitral ring **(white arrows)**. **(D)** The measurement of the Doppler gradients reveals relevant mitral stenosis (mean gradient: 12 mm Hg). LA = left atrium; LV = left ventricle; MV = mitral valve; RA = right atrium; RV = right ventricle.

by continuous-wave Doppler (in centimeters per second), and α is the opening angle of mitral leaflets relative to flow direction.

The PISA method is technically demanding, but it can be used in the presence of severe mitral regurgitation (MR). The integration of color M-mode, enabling simultaneous measurements of velocity and flow, improves the accuracy of this method (39).

According to Sugeng et al. (31), direct 3D planimetry from the left ventricular side is the most accurate method for MVA evaluation. The PISA method was the most accurate of all 2D techniques, followed by the PHT method, and 2D planimetry.

MEAN PRESSURE GRADIENT. Doppler measurements (transvalvular gradients) using the continuous-wave Doppler signal across the MV show good correlation with invasive measurements using transseptal catheterization (40). The Doppler diastolic mitral flow profile is traced, and the maximal and mean gradients are subsequently calculated automatically by integrated software (Fig. 4E). The maximal gradient is derived from peak mitral velocity and is strongly influenced by left atrial compliance and left ventricular diastolic function (41). The mean gradient is the major hemodynamic determinant of MS severity. Doppler measurements are highly heart rate and flow dependent because the transmitral gradient is a function of the square of the transvalvular flow rate and therefore dependent on the diastolic filling of the left ventricle (42). Despite these limitations, transvalvular gradients are very useful for the assessment of MS severity, particularly in patients in sinus rhythm.

PULMONARY ARTERY PRESSURE. The degree of pulmonary hypertension is an indicator of the overall hemodynamic consequences of MS, and severe pulmonary hypertension is associated with a decrease in mean survival of <3 years (43). Therefore, pulmonary pressures should be serially evaluated and followed in all patients with significant MS (21). The presence of more than mild MR (≥2+) is associated with worse outcomes (44) and is a relative contraindication to PMBV (20,21). Consequently, MR severity should be precisely categorized before a PMBV according to current guidelines (19,20). Concomitant valve diseases are frequently associated with rheumatic MS. Because stroke volumes are decreased in patients with MS, the severity of aortic stenosis may be underestimated. In patients with more than mild aortic regurgitation, the PHT method is not accurate.

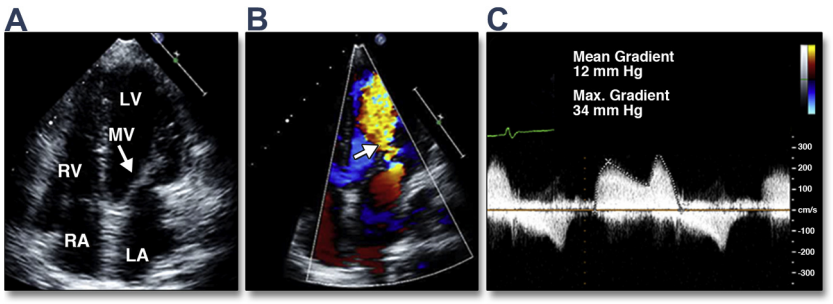

Figure 3. Example of a Congenital Mitral Stenosis

The case of a 45-year-old woman of short stature with geleophysic dysplasia is presented. **(A)** In the 4-chamber transthoracic view, the thickened and restrictive mitral leaflets are visible. **(B)** The accelerated flow through the stenotic mitral valve is shown. **(C)** Doppler gradients are evaluated. Abbreviations as in Figure 2.

STRESS TESTING. Assessing mitral gradients and pulmonary pressures during stress (preferably exercise or alternatively dobutamine infusion) (45) provides additional information in asymptomatic patients or in patients in whom the symptoms and MS severity do not seem to correlate. In addition, stress testing is very helpful in evaluating women with MS who are contemplating pregnancy. Pregnancy causes an obligatory increase in cardiac output (transmitral flow), heart rate (shorter diastolic filling time), and total blood volume, each of which increases the MV transvalvular gradient and thus left atrial pressure.

Consequently, many women with MS often present with symptoms for the first time during pregnancy due to the increase in pulmonary venous pressure (secondary to increased left atrial pressure). Exercise stress testing is a useful way to assess how well MS patients will tolerate pregnancy. It further helps identify which patients may benefit from no therapy, beta-blockade, or prophylactic PMBV or even surgery before becoming pregnant (46–50).

Assessment of valve anatomy and suitability for PMBV. Evaluation of the MV anatomy and pathology is a major aspect of the echocardiographic workup because this identifies the best treatment options. The pathological process of RF causes progressive leaflet thickening, calcification, and commissural and/or chordal fusion, thus resulting in narrowing of the MV orifice (51). Echocardiography is used to identify restricted leaflet motion in diastole, visible as "doming" of the anterior leaflet and immobility of the posterior leaflet (Fig. 1B) (52–54).

Furthermore, 2D echocardiography is used to evaluate morphological features including leaflet mobility and flexibility, leaflet thickness, leaflet

Table 1. Quantification of Mitral Stenosis Severity Using Various Methods

Method	Mild MS	Moderate MS	Severe MS	Limitations
Pressure half-time	Valve area in cm^2 Mild, >1.5; moderate, 1–1.5; severe, <1			Aortic regurgitation, atrial septal defect, previous surgical/percutaneous mitral valvuloplasty, net LA/LV compliance
Planimetry: tracing the inner edge of the mitral valve orifice in mid-diastole				Underestimation due to high gain
Continuity equation $\pi\left(\frac{D2}{4}\right)\left(\frac{\text{VTI aorta (cm)}}{\text{VTI mitral (cm)}}\right)$				Limited accuracy and reproducibility, atrial fibrillation, aortic/mitral regurgitation
Mean pressure gradient across the mitral valve: tracing of the Doppler diastolic mitral flow profile, mm Hg	<5	5–10	>10	Dependent on flow and heart rate
Systolic pulmonary artery pressure = tricuspid regurgitation gradient + RAP, mm Hg	<30	30–50	>50	Underestimation due to misalignment, inaccurate assessment of right atrial pressure

Adapted, with permission, from Bonow et al. (20).
LA = left atrium; LV = left ventricle; RAP = right atrial pressure; VTI = velocity time integral.

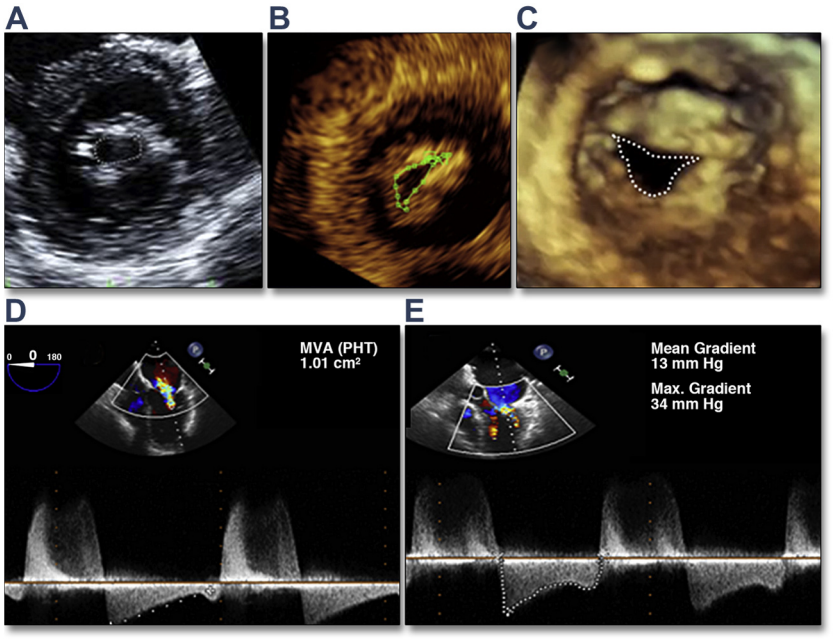

Figure 4. Different Methods to Evaluate the MVA and Assessment of Doppler Gradients

(A) A planimetric measurement in a transthoracic short-axis view is shown. **(B)** Using 3-dimensional (3D) transesophageal echocardiography (TEE), the planimetry is done in a post-processing step (Q-lab, Philips, Andover, Massachusetts). **(C)** The direct delineation of the MVA (mitral valve area) in a 3D TEE image (left ventricular aspect) is demonstrated. **(D)** The MVA is assessed by using pressure half-time (PHT), which is 218 ms (calculated valve area: 1.01 cm^2). **(E)** Mean and maximal Doppler gradients are obtained by tracing the Doppler diastolic mitral flow profile.

calcification, subvalvular fusion, commissural fusion, and calcification. These morphological features are used by different scoring systems (10,55–59) to describe the extent of the MV disease, to evaluate the suitability for PMBV, and to predict the success or even contraindication to PMBV. The following scoring systems have been validated in larger series and have been shown to be useful even though the predictive values of post-PMBV results are limited:

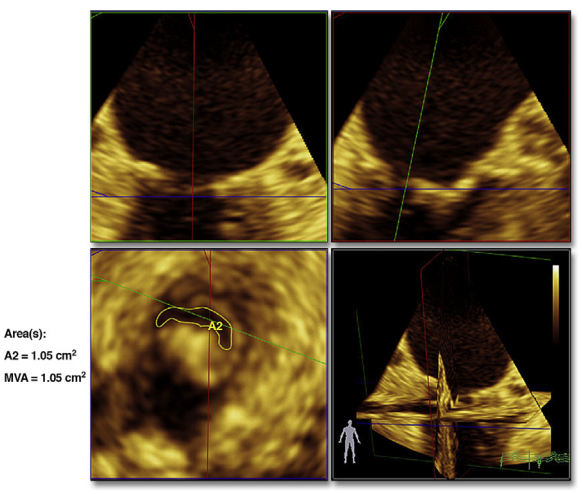

Figure 5. 3-Dimensional Transesophageal Measurement of the MVA

The multiplane method allows for exact definition of the orifice area at maximal opening during diastole. The calculated MVA (mitral valve area) is 1.05 cm^2.

- Wilkins score (58). This most commonly used 2D TTE assessment of the MV includes severity and extent of leaflet thickening, calcification, and involvement of the subvalvular apparatus. Each feature is graded on a scale of 1 to 4, yielding a maximal score of 16. A score >8 does not preclude PMBV, but is associated with less optimal results.
- Assessment of commissural calcium (Fig. 7) (59). With this method, the extent of commissural calcification is quantified by giving each half commissure (anterolateral and posteromedial) a score of 1 with the detection of high-intensity bright echoes. Commissural calcification can therefore range from grade 0 to grade 4. The grade of intercomissural

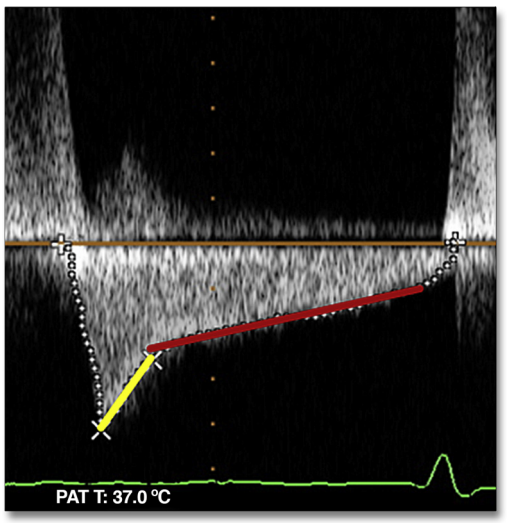

Figure 6. Example of a Bimodal Deceleration Slope

It is preferable to trace the deceleration slope in mid-diastole **(red line)** than tracing the early deceleration slope **(yellow line)**.

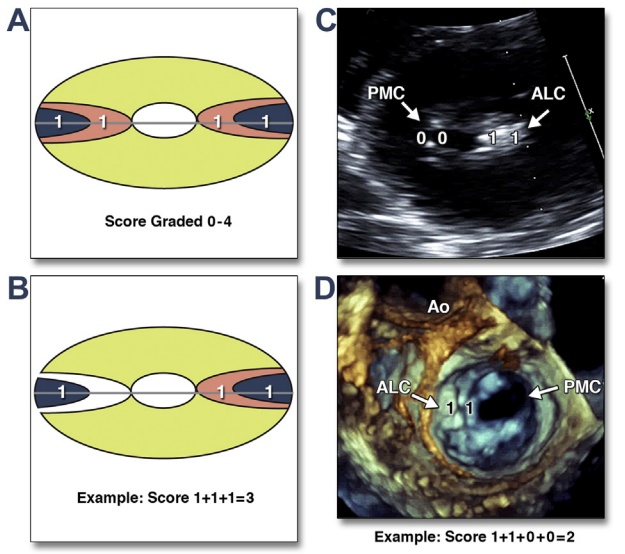

Figure 7. Evaluation of Commissural Calcification Score

Commissural calcification is quantified by giving a half commissure each (anterolateral and posteromedial) with detection of high-intensity bright echoes a score of 1. Commissural calcification can therefore range from grade 0 (no calcification) to grade 4. **(A)** Both commissures are completely calcified. **(B)** An example in which half a commissure is calcified on the left side and the entire commissure is calcified on the right side. The added score is therefore 3. **(C)** A 2-dimensional transthoracic short-axis view at the level of the mitral leaflets shows that only 1 commissure is completely calcified, whereas the other commissure shows no calcification. **(D)** The corresponding left atrial 3-dimensional transesophageal echocardiographic aspect is presented. The calculated score in this example is 2. ALC = anterolateral commissure; Ao = aorta; PMC = posteromedial commissure.

calcium is a predictor of achieving an MVA post-PMBV >1.5 cm^2 without creating significant MR. The influence was most evident in patients with a Wilkins score of ≤8 (i.e., patients who are likely to be amenable to PMBV), whereas the influence was not significant in patients with a Wilkins score >8. Patients with a commissural calcification grade 0/1 had larger valve areas and a better improvement of symptoms than patients with grade 2/3. Commissural calcification is a strong predictor of adverse outcomes of PMBV (60) as well as of the occurrence of severe MR as a major complication of PMBV (61).

- Echocardiographic grouping (Table 2) (10). The echocardiographic grouping is based on the echocardiographic and fluoroscopic (calcification) assessment of the following characteristics: valve mobility, fusion of the subvalvular apparatus, and the amount of leaflet calcification. It has been shown in a subset of patients that a Wilkins score in the range of 7 to 9 correlated with the echocardiographic group 1, a range of 8 to 12 correlated with the echocardiographic group 2, and a range of 10 to 15 with group 3 (62).
- Anwar et al. (63) (Table 3) introduced a score based on real-time 3-dimensional transthoracic echocardiography (RT-TT3DE) for the assessment of patients with MS before PMBV. This score includes the evaluation of both mitral leaflets and the subvalvular apparatus. The new RT-TT3DE score is feasible and highly reproducible with good

Table 2. Grouping of Mitral Anatomy as Assessed by 2-Dimensional Echocardiography and Fluoroscopy

	Group 1	Group 2	Group 3
Mitral valve anatomy	Pliable, noncalcified anterior mitral leaflet and mild subvalvular disease (thin chordae ≥10 mm long)	Pliable, noncalcified anterior mitral leaflet and severe subvalvular disease (thickened chordae <10 mm long)	Calcification of mitral valve of any extent, as assessed by fluoroscopy, no matter the state of the subvalvular apparatus

Table 3. Real-Time Transthoracic 3-Dimensional Echocardiographic Score for the Evaluation of Mitral Stenosis Before Percutaneous Mitral Balloon Valvuloplasty

	Anterior Mitral Leaflet			Posterior Mitral Leaflet		
	A1	A2	A3	P1	P2	P3
Thickness*	0–1	0–1	0–1	0–1	0–1	0–1
Mobility*	0–1	0–1	0–1	0–1	0–1	0–1
Calcification†	0–2	0–1	0–2	0–2	0–1	0–2

	Subvalvular Apparatus‡		
	Proximal Third	Middle Third	Distal Third
Thickness	0–1	0–1	0–1
Separation	0–2	0–2	0–2

The anterior and posterior leaflets are each divided into 3 segments (anterior leaflet: A1 [lateral segment], A2 [middle segment], A3 [medial segment]; posterior leaflet: P1 [lateral], P2 [middle], P3 [lateral]).*Each segment receives a separate score (either 0 for normal or 1 for abnormal) for thickness, mobility, and calcification. Normal score = 0, mild = 1 to 2, moderate = 3 to 4, severe = ≥5. †Absence of calcification is scored as 0, calcification in A2 or P2 (middle segments) is scored as 1, and calcification of commissural segments of both leaflets (A1, A3 and P1 and P3) is scored as 2. For calcifications: normal score = 0, mild = 1 to 2, moderate = 3 to 5, severe = ≥6. ‡The anterior and posterior chordae are scored at proximal (mitral valve level), middle, and distal (papillary muscle level) levels. At each level, the anterior and the posterior leaflet is scored for thickness and separation in between. Normal thickness is scored as 0, and abnormal thickness is scored as 1. Normal chordal separation (defined as distance >5 mm) is scored as 0, partial separation (defined as distance <5 mm) is scored as 1, and absence of separation is scored 2. The individual points are added, with the total score ranging from 0 to 31 points. Mild MV involvement is defined as <8 points, moderate MV involvement is 8 to 13, and severe MV involvement is >14 points. Adapted, with permission, from Anwar et al. (63).

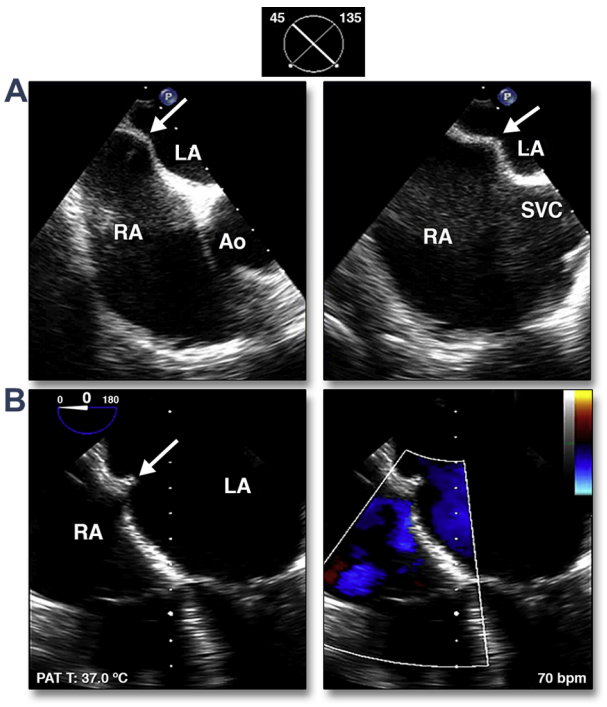

Figure 8. Transseptal Puncture

(A) Determination of the puncture site is shown in a transesophageal echocardiography (TEE) x-plane view. A short-axis view **(left side)** and a long-axis view **(right side)** are presented simultaneously. The "tenting" of the interatrial septum (caused by the transseptal needle) is marked with **white arrows (A, B)**. **(B)** A 4-chamber view (TEE 0°) without **(left)** and with **(right)** color Doppler demonstrates the evaluation of the height above the mitral valve. SVC = superior vena cava; other abbreviations as in Figures 2 and 7.

interobserver and intraobserver agreement in the assessment of MV morphology in patients with MS. RT-TT3DE is better able to detect calcification and commissural splitting. Predictors of optimal PMBV results by the 3D scoring system are leaflet mobility and the involvement of the subvalvular apparatus. The incidence and severity of post-procedural MR are associated with a high RT-TT3DE calcification score.

No individual scoring system is clearly superior to another. Thus, the scoring systems should be used in a complementary fashion, as a part of the comprehensive echocardiographic assessment of the MV pathology and function.

Unfortunately all scoring systems are limited by variable reproducibility because all scores are semiquantitative; lesions may be underestimated, particularly with regard to the extension of the subvalvular disease, and scores that describe the overall degree of MV pathology may not adequately identify localized abnormalities in specific parts of the MV and the MV apparatus, which may increase the risk of MR.

Many interventionalists consider or even recommend PMBV in patients with a high overall echocardiographic score, when commissural fusion is present, and when other clinical features are favorable.

Contraindications to PMBV should be excluded (MVA >1.5 cm^2, left atrial/left atrial appendage thrombus, MR that is more than mild, severe or

bicommissural calcification, the absence of commissural fusion, severe concomitant valve disease, concomitant coronary artery disease requiring bypass surgery) (19). PMBV is relatively contraindicated in MS not due to commissural fusion because it is the "splitting" and opening of fused commissures that is the mechanism that increases the MVA.

In asymptomatic patients with mild to moderate MS (MVA >1.5 cm^2), neither PMBV nor surgery is warranted; however, these patients should have clinical and echocardiographic examinations every 2 years. Asymptomatic patients with severe MS (MVA ≤1 cm^2) should be evaluated annually (20). MS is a progressive disorder, and the MVA generally decreases by ~0.1 cm^2 per year.

ECHOCARDIOGRAPHIC ASSESSMENT DURING PMBV. Different types of balloons can be used for PMBV (single balloon, double balloon, Inoue balloon). The Inoue balloon (Toray Medical Co., Ltd., Chiba, Japan) is the most commonly used balloon and is associated with a high success rate (>95%) and a very low hospital mortality rate. After PMBV, the MVA increases to an average of 1.9 to 2.0 cm. Good immediate results are obtained in nearly 90% of patients, with 60% improving to New York Heart Association functional class I and 30% to functional class II (17).

The procedure is usually performed in the cardiac catheterization laboratory with the patient under either conscious sedation or general anesthesia. Because thrombi can develop and enlarge rapidly in the setting of MS and stasis within the left atrium and left atrial appendage, the presence of intracardiac thrombi should be excluded before the transseptal puncture. This is even more problematic if anticoagulation therapy is discontinued before PMBV. TEE has excellent sensitivity and specificity and is the imaging procedure of choice to detect thrombi in patients with MS and is therefore recommended before PMBV (64). In case of difficulties in differentiating between a thrombus and

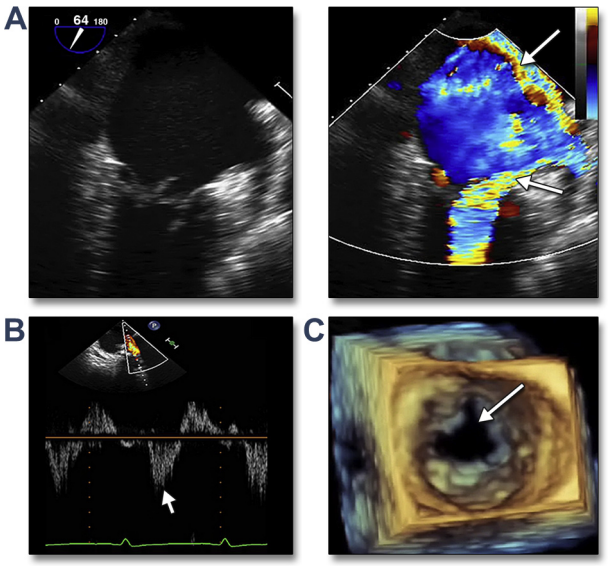

Figure 9. Suboptimal Result After Percutaneous Mitral Balloon Valvuloplasty

(A) Severe eccentric, mitral regurgitation is present (**white arrows** follow the jet in the left atrium). **(B)** The pulmonary vein flow pulsed-wave Doppler profile demonstrates a reversed flow in systole **(short white arrow)**, thus indicating severe mitral regurgitation. **(C)** The commissures are split after percutaneous mitral balloon valvuloplasty; in addition, an anterior leaflet rupture can be identified **(long white arrow)**.

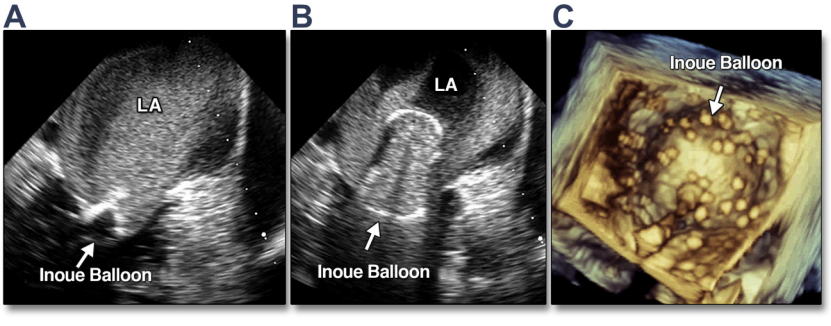

Figure 10. Stasis in the LA During Balloon Inflation

The Inoue balloon is inflated at the mitral valve. **(A)** Only the distal part of the balloon is inflated. **(B)** The entire balloon is inflated. **(C)** A 3-dimensional transesophageal en face view from the LA side showing the inflated balloon. Dense spontaneous echocardiographic contrast indicates stasis in the LA **(A, B)**. LA = left atrium.

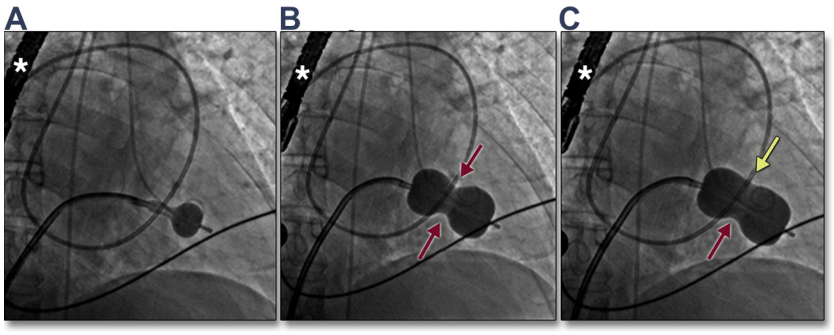

Figure 11. Mitral Commissurotomy Technique With the Inoue Balloon

(A) The inflation of the distal portion of the balloon is seen fluoroscopically. Thereafter, the balloon is pulled back at the mitral valve. **(B)** A subsequent inflation of the proximal and middle portions of the balloon follows. A waist in the mid-portion of the balloon on both sides **(red arrows)** indicates that both commissures are still fused. **(C)** The balloon is fully inflated. The disappearance of the waist on one side **(yellow arrow)** indicates that this commissure is split, whereas the opposite commissure remains fused **(red arrow)**. The **asterisks** mark the transesophageal echocardiography probe.

dense spontaneous echocardiographic contrast, the use of contrast agents may be useful. Whether this distinction affects a patient's management and/or prognosis has not been studied. The presence of a thrombus in either the left atrium or left atrial appendage is considered as a relative contraindication to PMBV. If a thrombus is detected, the procedure should be postponed until the thrombus resolves on future TEE evaluation. If the thrombus does not resolve, surgery is considered the preferred treatment option. However, some interventionalists have shown that it is feasible to perform PMBV using a modified Inoue technique in selected patients with laminar thrombus confined to the left atrial appendage, particularly after 4 to 6 weeks of effective anticoagulation treatment (65). Nonetheless, our recommended approach is to avoid PMBV in the setting of thrombi due to the potential risk of iatrogenic catastrophic stroke.

For most PMBV cases, the preferred puncture site for transseptal access to the left atrium is in the posterior, more inferior region of the fossa ovalis. Many operators rely primarily on fluoroscopic guidance, but TEE or, alternatively, intracardiac echocardiographic guidance is helpful, especially in patients with a large atrium or unusual morphology of the interatrial septum (IAS). The IAS morphology may be altered in the setting of a large atrial septum aneurysm, previous cardiac surgery, or percutaneous procedures involving the

Table 4. Predictors of Outcome After Percutaneous Mitral Balloon Valvuloplasty

Predictors of Good Outcome	Predictors of Poor Outcome
Commissural calcium grade 0/1 (60,61)	Age >65 yrs (10,62,70,71)
Wilkins score <8 (12,49,58,72,73)	Wilkins score >8 (12,50,58,71,73)
Sinus rhythm (15,72,74)	Smaller initial MVA (10,62)
Good leaflet mobility (63)	Use of the double-balloon technique (62)
No involvement of the subvalvular apparatus (63)	High echocardiographic group (62)
Age ≤65 yrs (70,73)	Commissural calcium grade 2/3 (59,60)
Larger pre-procedural MVA (72)	Valvular calcification and severe subvalvular lesions (12)
Normal mean pulmonary artery pressure (70)	Previous commissurotomy (10)
MR grade post-procedure ≤2 (15,72)	Baseline mitral regurgitation (10)
Complete commissural opening (75)	Lower MVA post-procedure (63,70)
Larger MVA post procedure (72,73,75)	Elevated post-procedural pulmonary artery pressure (71,76)
Absence of calcium at fluoroscopy (74)	Post-procedural MR ≥3+ (71)
Reduction in left atrial pressures post procedure (72)	Previous surgical commissurotomy (62,71)
Lower MV gradient pressures post procedure (70,72)	New York Heart Association functional class IV (71)
Echocardiographic grouping score <3 (59,70)	Echocardiographic grouping score of 3 (59,70)

MR = mitral regurgitation; MV = mitral valve; MVA = mitral valve area.

Table 5. Mechanisms of Potential Complications During Percutaneous Mitral Balloon Valvuloplasty

Mechanisms	Complication	Treatment/Prevention
Catheter, guidewire, or transseptal needle perforation of LA and LV	Pericardial effusion/tamponade (incidence 0%–2%) (75–83)	Pericardial drainage Surgery if needed
Large sheaths, which allow air into the circulation	Air embolism	Aspiration and flushing of catheter as well as keeping catheter hub lower than the level of heart during catheter insertion or removal De-airing of the balloon
Thrombus formation on catheters or wires during the procedure	New occurrence of thrombus formation	Maintain ACT of between 250 and 300 s
Inadequate assessment before the procedure	Thrombotic embolism (incidence 0%–4%) (70,72,73,82–86)	Adequate assessment for thrombus before the procedure Eliminate thrombus before PMBV
Excessive tearing of 1 or both commissures, a rupture of a leaflet in a noncommissural area (Fig. 9), insufficient closure of a calcified leaflet or a rupture of structures of the subvalvular apparatus	MR (incidence 1.4%–9.1%) (50,70,72,73,82–86)	Choice of balloon size according to patient's characteristics Echocardiographic monitoring of balloon dilation of the MV Discontinue PMBV if MR >1+ occurs ± signs of leaflet tearing In case of severe MR, consider placement of an intra-aortic balloon pump and emergent surgical treatment (mostly valve replacement) due to acute hemodynamic deterioration from acute severe MR after PMBV
Large transseptal sheath placement	Persistent ASD	Most remain small and require no treatment (87); if there is a right-to-left shunt causing hypoxemia, closure either percutaneously or surgically is warranted

ACT = activated clotting time; ASD = atrial septum defect; PMBV = percutaneous mitral balloon valvuloplasty; other abbreviations as in Tables 1 and 4.

IAS or distortion of the IAS due to severe scoliosis or previous pneumonectomy. A Brockenbrough needle is usually used for transseptal puncture, its tip identified by a tentlike deformation ("tenting") of the IAS on TEE, as illustrated in Figure 8. The height above the valve is best appreciated in a 4-chamber view (~0°) (Fig. 8B), the anteroposterior orientation can be obtained by using a short-axis view at the base (~30° to 45°) and superoinferior orientation is given by a long-axis view (~90° to 100°). X-plane imaging allows for anteroposterior and superoinferior orientation simultaneously thus facilitating the transseptal puncture (Fig. 8A).

Choosing the appropriate balloon size is important to minimize the risk of leaflet tearing and avoiding injury to the mitral apparatus. Different methods have been proposed based either on the height of the patient (66) or the body surface area (67) or using the simple formula: height (cm)/10 + 10 (68). However, the relationship between height and body surface area does not necessarily correlate linearly with the MVA. In addition, annular calcification has also to be taken into consideration because it also affects the MV orifice. Balloon size choice may be optimized by the echocardiographic measurement of the maximal intercommissural diameter on a parasternal short-axis view from the anterolateral to the posteromedial commissure in mid-diastole (69). The balloon is placed from the left atrium across the MV orifice and into the left ventricle. Fluoroscopy is used primarily, but additionally TEE (or intracardiac echocardiography) is helpful to avoid catheters and wires entering the left atrial appendage, to guide the balloon into the MV, and to determine the best position of the balloon between the mitral leaflets by using x-plane views. It is critical to avoid inflation of the balloon in the subvalvular region as this can result in chordal rupture, tearing of the valve leaflet at a site other than the commissures, and even damage to and tearing of the papillary muscle (Fig. 9). During balloon inflation, the MV orifice is completely occluded and transient, reversible hemodynamic deterioration frequently occurs, as can be seen in Figure 10. Therefore, close monitoring of hemodynamic parameters is mandatory during this phase of the procedure. Splitting of the commissures can be identified fluoroscopically when the constriction, visible at the least compliant portion in the waist of the balloon at the level of the mitral leaflets, suddenly disappears, as shown in Figure 11.

Criteria for concluding a PMBV procedure include an MVA >1 cm^2/m^2 body surface area,

complete commissural opening in at least 1 commissure, and occurrence of or increase in MR >1+. Meticulous attention to procedural details is important in high-risk patients such as the elderly patients, pregnant patients, and patients with severe MS, extensive subvalvular involvement, nodular commissural calcification as well as in patients in whom the MV opens asymmetrically.

According to the American College of Cardiology/American Heart Association guidelines, successful PMBV is usually defined as an MVA ≥1.5 cm^2 and absence of complications (including MR > grade 2/4) (20).

In cases with suboptimal results, balloon inflation is repeated by increasing the balloon size in 1-mm increments until a satisfactory MV opening is achieved or a relevant worsening of MR occurs.

The prediction of results after PMBV is multifactorial and includes a variety of clinical, morphological, and hemodynamic parameters. Table 4 provides an overview of predictors of good and poor immediate and long-term results (70–76).

ASSESSMENT AFTER PMBV. Immediately after balloon inflation, left atrial pressure should be obtained and echocardiography is used to evaluate a post-PMBV MVA using mean Doppler gradients and 2D and 3D MV planimetry, reassess commissural opening, evaluate MV leaflet mobility, determine the severity and location of MR, and assess complications.

In the post-procedural evaluation of MVA planimetry, using real-time 3D echocardiography has been shown to be more accurate and to have the best agreement with invasively determined MVA compared with conventional 2D planimetry (77). In addition, the opening of the commissures is shown more clearly by real-time 3D echocardiography. Commissural opening is a significant predictor of long-term outcome and is associated with a larger MVA, smaller gradients, and better functional outcomes (75). After PMBV, the PHT method for MVA assessment should not be used because it is often inaccurate (36,78) due to the newly created atrial septal defect in many patients, the changes in hemodynamic variables that influence the measurement, and the alteration in the compliance of the left ventricle and left atrium after PMBV. Moreover, there is poor agreement between PHT with invasive measurements after PMBV (14,79,80).

COMPLICATIONS DURING PMBV. Complications may occur at any time during the procedure, and their detection by echocardiographic monitoring is important. Table 5 summarizes potential complications during PMBV, their mechanisms and prevention, and treatment options (70,72,73,81–87).

Conclusions

Although the incidence of RF and the prevalence of rheumatic heart disease is decreasing in industrialized countries, a substantial occurrence of rheumatic MV disease exists worldwide, especially in developing countries. PMBV is an important treatment option for this condition. Therefore, adequate understanding of the indications, patient selection, PMBV procedures, and assessment of results is of paramount importance.

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Key Words: echocardiography ■ mitral stenosis ■ percutaneous intervention ■ percutaneous mitral balloon valvuloplasty ■ rheumatic heart disease.

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